The Effects of Electric Utility Decoupling on Energy Efficiency

Jenya Kahn-Lang[1]

In partial fulfillment of a Bachelor of Arts Degree in Economics and Environmental Analysis,

2011-12 academic year, Pomona College, Claremont, California

[1] I would like to thank Professor Bowman Cutter for his encouragement and feedback throughout the course of this project. His constant support and direction made this project a possibility. I am extremely appreciative to professors John Jurewitz and Pierangelo De Pace for sharing their expertise in their respective fields with me. I would also like to thank Professors Gary Smith, Eleanor Brown, and Char Miller for their indispensible assistance and enthusiasm. Finally, I could not possibly thank my parents enough for all of their help over the years and with this project.

Abstract

Traditional utility regulation exacerbates energy inefficiency by creating an incentive to encourage overconsumption of energy. Revenue decoupling mechanisms eliminate this throughput incentive, but critics argue that decoupled utilities will still not actively promote energy efficiency. This paper models the interplay between utility DSM investment and regulator incentives and standards. It explores the hypothesis that decoupling mechanisms decrease residential electricity consumption, but only through their effect on the level, direct demand-reducing effects, and indirect demand-reducing effects through price of DSM investment. It then empirically analyzes the effects of decoupling mechanisms on residential per-customer electricity use. The findings suggest that decoupling mechanisms do significantly decrease residential electricity consumption overall, but that this significance disappears when the effects of decoupling mechanisms on retail electricity price and DSM investment are properly accounted for. Results indicate that decoupling mechanisms increase the direct and indirect demand-reducing effects of DSM investment. Findings concerning the relation between decoupling mechanisms and level of DSM spending suggest a positive correlation, but they are inconclusive due to limited sample size.

Table of Contents

Introduction

Overconsumption of energy is the source of two of the largest issues facing today's world: global climate change (Stern 2008) and energy security (Brookings 2011). Energy demand is increasing worldwide and is projected to continue increasing, at annual average rates of about 3.2% and 1.1% for emerging and mature economies respectively (Asif and Muneer 2005). As a result, scientists project a continuation of the trends of increasing air pollution, especially carbon dioxide (CO_2) and other Greenhouse Gas (GHG) pollution related to climate change, and a decreasing stock of non-renewable energy sources (Smil 2010).

Inefficient energy use is exacerbating global climate change. Fossil fuel combustion is the primary cause of the 80% increase in CO_2 emissions between 1970 and 2004 (IPCC 2007). Coal-fired power plants emit about 1 ton of CO_2 for every Megawatt of electricity provided to customers (Hurley et al. 2008). While the exact costs of global climate change are currently in debate, with numerous estimates around 3-5% of gross domestic product (GDP) per year, climate change is arguably the largest market failure present in today's world. Due to environmental and health externalities associated with GHG emissions, the costs associated with failing to adequately mitigate climate change considerably exceed the mitigation costs (Stern 2006, Ackerman and Stanton 2008).

Since the majority of the world's energy comes from finite, rapidly depleting sources (Smil 2010), which are located in only a few specific countries, many people worry about the sustained attainability of energy. The US, like many other countries including China, India, and UK, relies heavily on energy importation to fulfill its growing demand. US oil reserves could sustain the country's demand for less than 4 years (Asif and Muneer 2005). Worldwide, fossil fuels are getting increasingly difficult and less cost-effective to obtain and convert into useful forms of energy. Inevitably, society will need to transition to a post-fossil fuel world, but there is a lot of uncertainty regarding the timing and details of this process (Smil 2010).

While production-based technological advances will probably be part of the solution, increased energy efficiency and decreased energy consumption is essential for effective climate change mitigation and for improvements to energy security. Due to the scale of necessary carbon storage, it is unlikely that people could capture and store an adequate fraction of our current carbon emissions through carbon sequestration methods (Bryce 2010). During the continued period of heavy reliance on fossil fuels, therefore, a substantial reduction in emissions must be a result of lower demand for energy production. Furthermore, while there are many potential sources of energy in an inevitable post-fossil fuel energy regime, they are all limited in the potential useful energy they could provide society. Experts agree that the future energy regime will most likely need to cope with lower energy and power densities by decreasing energy consumption (Smil 2010). According to the Environmental Protection Agency (EPA) (2007), increasing energy efficiency in residential, business, and industrial sectors is one of the most cost-effective ways to address the issues of energy security, air pollution, and climate change.

There currently exist many cost-effective and negative cost opportunities in energy efficiency, but, for the most part, people do not seem to be capitalizing on these opportunities (Gillingham, Newell, and Palmer 2009). For example, many consumers have yet to replace their inefficient incandescent light bulbs with efficient compact-fluorescent light bulbs (CFL's) or light-emitting diode (LED) fixtures, even though doing so would save the consumer money and decrease energy use (McKinsey 2007; Energy Star 2012). Economists have suggested a multitude of reasons for this abundance of seemingly irrational decision-making. The main implication of these studies is that consumers need external assistance in making efficient energy decisions.

Utility promotion of energy efficiency is valuable. Utilities promote energy efficiency through various demand-side-management (DSM) programs that aim to alter the level and timing of consumer energy consumption. These programs include assisting consumers practically and financially in installing energy efficient technologies, educating consumers about energy consumption management, and instituting pricing schemes intended to transform consumer incentives. DSM programs exist for industrial, commercial, and residential customers (Loughran and

Kulick 2004). Gillingham, Newell and Palmer (2006) found that utility-based demand-side-management (DSM) programs produced greater energy reductions than government or third-party DSM efforts. Train and Stebel (1987) found that people are skeptical that specific supposedly energy-efficient devices will be cost-effective and that this skepticism is reduced when utilities offer rebates.

Under traditional energy utility regulation, however, utilities are incentivized to encourage inefficient energy use. This phenomenon is known as the *throughput incentive* of electric and natural gas utilities. As it is a substantial barrier to utility promotion of energy efficiency, it is important to address this incentive structure.

One mechanism that can be implemented to address the throughput incentive issue and thereby encourage energy efficiency is *decoupling*, in which revenues are partially or fully detached from and unaffected by sales quantities. While a decoupling mechanism eliminates a utility's aversion to demand side management (DSM), there is some debate over whether these mechanisms encourage utilities to actively invest in DSM and to promote energy efficiency (NARUC 2007).

This paper aims to address the question of whether decoupling mechanisms promote energy-efficient practices and cost-effective changes in energy consumption in practice through analysis of historical trends in energy consumption. It begins by reviewing the existing literature on the subject and performing economic modeling to explore the interplay between utility DSM investment and regulator incentives and standards. Econometric techniques are then utilized to analyze the empirical relation between decoupling mechanisms and residential electricity consumption. Finally, this paper addresses some potential concerns with the underlying assumptions made in this analysis and presents some robustness tests on the results.

Literature Review

Energy Inefficiency

Heightened awareness about the harmful effects of GHG emissions and widespread concerns about energy security have sparked increased research on energy efficiency over the past few decades. Numerous academics have attempted to uncover the structural and behavioral factors that affect energy consumption and energy efficiency investment (Glaeser and Kahn 2008, Baumann 2008). Others have focused on understanding the reasons that some people support energy efficiency measures and choose to participate in energy efficiency programs while others do not (Musti, Kortum, and Kockelman 2011, Kotchen and Moore 2007, Costa and Kahn 2010).

Despite increased awareness about the need for energy efficiency and improved understanding of energy efficient practices, homeowners are not investing in energy efficiency as much as they should (Brennan 2009b). Historically, consumers have acted as if they had about 25% discount rate in their choices of investing in conservation, which is substantially higher than most estimates of the prevailing social discount rate (Hausman 1979). Gallup polls throughout the past decade show that Americans believe that conservation, as opposed to increased fossil fuel production, is the key to addressing the nation's energy problems (Saad 2011). Brennan (2009b) attributes this discrepancy between beliefs and actions to consumer choice failure. Gillingham, Newell, and Palmer (2009) identify heuristic decision-making and bounded rationality as potential causes of consumer choice failure regarding energy efficiency. In other words, decisions consumers make about energy efficiency are often irrational due to lack of available information, human cognitive limitations, the cognitive burden of decision-making and the time it takes to make decisions. Gillingham, Newell, and Palmer (2009) also recognize prospect theory as a potential behavioral failure. Prospect theory states that people are hesitant to change their behavior, such as investing in energy efficiency if they are unsure of the potential costs and benefits because they are disproportionately averse to potential losses relative to potential gains. Gillingham, Newell, and Palmer

(2009) found that consumers often ignore energy efficiency in purchasing decisions because they cannot distinguish between products that are more energy efficient and products that are less energy efficient since all products are being advertised as being energy efficient.

Another source of inefficiencies in energy use stems from a concept known as the principal-agent problem. People who use energy in a building yet do not pay utility bills, such as many renters, have no incentive to minimize their energy use or to invest in energy efficiency. The residents make the decision about how much energy to consume and how much money to invest in future energy savings, but they do not experience any of the private costs of their chosen actions. As a result, they tend to over-consume and under-invest compared to the efficient set of actions (Gillingham, Newell, & Palmer 2009). Increased utility DSM programs may somewhat increase the energy efficiency of such residents due to environmental consciousness, but neither DSM programs nor utility price structures tackle the core inefficiency of the principal-agent issue.

Traditional Regulation

Under traditional regulation, the rates of an electric utility are established by an external party during a general *rate case*, which usually occur every 3-6 years, or, in some states only at the request of the utility (Ohio PUCO 2011, Wisconsin PSC 2001).

In a rate case, the third party examines all of the utility's expenses during a past or future test year, hears testimonies from all interested parties, and determines a *revenue requirement*, or the revenue necessary to cover the utility's expenses and taxes and to give a fair rate of return on investment (Lazer, Weston, and Shirley 2011, Ohio PUCO 2011, Wisconsin PSC 2001). Fixed costs and costs associated with depreciation are included in the determination of utility expenses (EPA 2007). The third party regulator often holds formal hearing to hear testimonies of all interested parties, including utility representatives, customers, and investors. In many states, the utilities can apply for a rehearing if they are dissatisfied with the regulator's decision. In some extreme cases, utilities can even bring rate cases to the state supreme court (Ohio PUCO 2011).

Once a revenue requirement is finalized, the allowed revenue is then divided by the number of units of electricity sold (or expected to be sold) during the test period in order to determine the utility's average electricity rate for the next period. The average rates are often computed separately for each customer class[2]. These average rates are essentially constant until the utility next undergoes a rate case. (Lazer, Weston, and Shirley 2011)

One notable aspect of an electric utility's cost structure is that the utility incurs virtually no net marginal costs per unit of electricity produced. The potential marginal costs of a utility would be labor, distribution, and fuel costs. However, labor and distribution costs vary with number and location of customers and are essentially not affected by per-customer energy use. The only costs related to energy use are fuel costs, but these are *pass-throughs*, or costs that are directly transferred to customers. Variation in fuel costs usually appears as a monthly tariff or credit on customer bills, often referred to as *fuel adjustment clauses* or *power cost adjustments* (Ener Star 2012). Each month, the utility recalculates the fuel cost associated with each customer based on the month's fuel prices and the customer's electricity consumption and charges the customer exactly that amount.

Another notable aspect of a traditionally regulated utility's rate structure is that if actual revenue during the time period between rate cases differs from expected revenue for any reason not covered by adjustment clauses, the utility gains a profit or suffers a loss. Utilities have substantial fixed costs that require adequate revenue to finance. These include sunk capital costs associated with increasing generation capacity, building transmission lines, and DSM investments. If revenue does not reach the threshold value of covering fixed costs, the utility suffers a loss. (CSI 2008)

---

[2] Many utilities vary rate schedules by customer class. Customer classes group customers with similar demand characteristics together (ex- small, residential customers).

Under the traditional structure of regulation, utilities are deterred from investing in energy efficiency and even have incentives to actively lobby against energy efficiency in favor of decreasing efficiency. Brennan (2008) argues that utilities only have incentives to promote energy efficiency and other demand-reductions if price caps cause prices to fall below marginal costs but that when prices are greater than marginal costs, utilities have incentives to increase *throughput* i.e. electricity usage. In almost all instances, regulated retail prices do surmount marginal costs (EIA 1997). Thus, in the periods between rate cases, the utility has an incentive to increase revenues above what had been expected by the rates set by increasing electricity sold. This is known as a *throughput incentive* and is a major barrier to the utility promotion of energy efficiency (EPA 2007). Increased energy efficiency decreases throughput, so the utilities have an incentive to actively oppose energy efficiency programs. If utilities nevertheless do create programs to promote energy efficiency, not only do they lose revenues from electricity sales, but they also have to cover spending on program implementation. This can lead to losses (known as *lost margin recovery*). An investigation by Idaho Power Company found that, in practice, revenue loss from energy efficiency programs does indeed decrease a utility's recovery of fixed costs, which produces barriers to utility investment in demand-reducing energy efficiency programs (EPA 2007).

Suggested Solutions Concerning the Throughput Incentive and Energy Efficiency

This section briefly discusses the merits and drawbacks of four prominent proposals for addressing the throughput incentive problem: government monetary incentives, other types of third party promotion mechanisms, straight fixed-variable rate designs, and real-time pricing.

One proposal is that the government should provide monetary incentives to utilities for investing in energy efficiency. While this would assist in covering the costs of utility-sponsored DSM programs, monetary incentives alone would probably not be effective, as the incentive must be sufficient to cover the costs of program implementation and compensate for lost margins. Such incentives, if not designed with adequate care, may also cause utilities to invest a lot of money in energy efficiency programs that are not particularly cost-effective (Lazer, Weston, and Shirley 2011).

More generally, many promoters of energy efficiency argue that a third party, and not utilities, should be responsible for encouraging energy efficiency. They contend that utilities are innately not in the best position to promote energy efficiency. Utilities have an advantage over third-party energy-efficiency providers, however, as they have more complete information and records about energy use. More importantly, a third-party energy-efficiency provider would be most effective if the utility's throughput incentive could be eliminated (by decoupling, for instance), as this would eradicate lobbying against the third party and would increase the likelihood of relevant information disclosure. In Vermont and Oregon, third-party energy-efficiency providers found decoupling to be a helpful addition to their own encouragement of energy efficiency (Lazer, Weston, and Shirley 2011).

Another proposal is implementation of a straight fixed-variable (SFV) rate design (Lesh 2009). Under SFV, there is a large mandatory, non-volume-based charge for all customers that covers all or most of the utility's fixed costs, rendering variable costs closer to the true marginal cost of producing electricity. This decreases and can even eliminate the throughput incentive. However, SFV rate designs simultaneously discourage energy efficiency by decreasing the incentive for consumers to reduce their energy use through lower usage (marginal) costs. In addition, SFV is regressive (EPA 2007). Since low-income households tend to consume less energy, a larger fixed charge will disproportionately burden low-income households. Boonin (2009) promotes a SFV design combined with a Revenue-Neutral Energy Efficiency Feebate (REEF), which theoretically counteracts the regressive nature of the SFV design and reestablishes customer incentives to decrease energy use. Unfortunately, it may be difficult and administratively costly to construct a feebate system that accurately determines individual energy efficiency and appropriately counteracts the regressive nature of SFV.

Real time pricing (RTP) of electricity has been suggested as a method of increasing energy efficiency, limiting market power of utilities, and reducing electricity demand variance (Holland and Mansur 2008). With RTP, utilities set prices as a function of actual demand at the given time. According to economic theory, this causes a disincentive to use electricity during hours of peak demand, which, due to variability in efficiency of generation equipment, should have a disproportionate positive effect on the environment (Holland and Mansur 2008). In contrast, Ito (2010) found that actual household-electricity-use data suggests that consumers respond to average prices instead of marginal prices, which lowers projected estimates of decreases in peak demand due to RTP.

Decoupling Mechanisms - Overview

Decoupling mechanisms address the throughput incentive by fully or partially detaching utility revenues from sales. Under a decoupling mechanism, the *allowed revenues* are set during a general rate case, and rates are adjusted during regular, periodic *true-ups* that keep long run revenue equal to allowed revenue by changing prices. If the utility makes less revenue than expected in a given period, then rates are increased or a surcharge is added in the following period. Conversely, if there is a surplus in revenue, the money is refunded to the customers in the form of lower rates, lump sum tariffs, or other reconciliation mechanisms (EPA 2007). Note that no reassessments of costs or allowed revenue are performed during true-ups (Lazer, Weston, and Shirley 2011).

There are a variety of decoupling mechanisms. One difference between them is the effect of increasing the utility's customer base. Under straight *revenue decoupling*, an increase in customers does not change a utility's allowed revenues and, as a result, tends to hurt rather than help the utility. *Revenue per customer (RPC)* decoupling, however, fixes allowed revenue per customer. Thus allowed revenue during any given time period is determined by the following formula:

Allowed Revenue = (Allowed Revenues per Customer)(# of Customers)*

RPC decoupling could discourage utilities from increasing their customer base if new customers were higher energy users. Some RPC decoupling mechanisms address this issue by including different allowed RPC's for new and existing customers. (Lazer, Weston, and Shirley 2011)

Decoupling mechanisms also differ with regard to the frequency of true-ups. Utilities with *accrual decoupling* mechanisms only undergo annual true-ups, while those with *current decoupling* experience true-ups every billing period. True-ups for other decoupled utilities may occur on a quarter- or semi-annual basis (Lazer, Weston, and Shirley 2011).

Another way decoupling schemes differ is by the reasons allowed for revenue adjustments during true-ups. A *fully decoupled* utility adjusts for any deviation of actual revenues from allowed revenues, regardless of the cause of these deviations. A utility with *partial decoupling* adjusts for a certain, fixed percentage of the departure of actual revenue from allowed revenues during true-ups. Partial decoupling mechanisms also do not discriminate based on cause of revenue deviations. Partial decoupling reduces the throughput incentive without completely eliminating it. During a true-up for a utility with *limited decoupling*, disparities between actual revenues and allowed revenues may or may not lead to adjustments depending on the cause of the disparities. One common example of limited decoupling is utilities that have only *lost-margin mechanisms*, where adjustments for revenue decreases are only made if the decreases can be explicitly identified as the result of DSM programs. If executed correctly, limited decoupling eliminates the throughput disincentive associated with energy efficiency programs without eliminating utility responsibility to provide coverage and assume risk due to other causes, such as economic fluctuations. The largest drawback of limited decoupling is its relatively high administrative and monitoring costs compared to other forms of decoupling (Lazer, Weston, and Shirley 2011).

Other decoupling mechanisms include attrition adjustments, inflation minus productivity adjustments, and K factor adjustments. *Attrition adjustments* are essentially annual abbreviated rate cases when allowed revenues are reassessed and altered slightly in response to known and measurable changes in a utility's costs. This mechanism decreases the need for frequent full rate cases if a utility does not undergo a large structural change. *Inflation minus productivity adjustments* alter allowed revenues in response to shifts in inflation or productivity. This mechanism, along with regular true-ups, also decreases the need for frequent full rate cases. Another mechanism to change allowed revenues between rate cases is known as *K-factor adjustment.* A K factor adjustment is a predetermined, usually annual, rate increase or decrease between rate cases. For example, a utility might receive a 1% annual increase in allowed revenues between rate cases. The K factor itself can be designed to change over time if growth is not predicted to be linear, or can be applied to allowed revenues *per customer* instead of total allowed revenues. Although all three of these mechanisms aim to reduce the need for frequent rate cases, occasional rate cases are still necessary with all three of these decoupling mechanisms.

Arguments for the Implementation of Decoupling Mechanisms

Decoupling mechanisms are attractive for several reasons. They are beneficial to the environment (Graniere and Cooley 1994) and are more politically feasible than many mechanisms to promote energy efficiency. They encourage energy efficiency by eliminating a political barrier to energy efficiency promotion, removing an economic barrier to utility energy efficiency investment, and partially shifting the responsibility of making energy efficiency decisions from consumers to suppliers. Decoupling mechanisms are politically feasible, as they involve relatively low administrative costs and are structured in a way that fosters utility support.

From an energy-efficiency standpoint, the decoupling-caused elimination or reduction in the utility throughput incentive is essential for utility or third-party promotion energy efficiency. For one, the removal of a throughput disincentive decreases or eliminates utilities' political opposition to public energy efficiency programs and government measures (Brennan 2009a). Moreover, the decoupling incentive structure also renders utilities more willing to take actions themselves that encourage energy efficiency. For instance, under decoupling mechanisms, utilities are more willing to institute rate designs that encourage energy efficiency (Lazer, Weston, and Shirley 2011).

Brennan (2008, 2009a) argues that decoupling is fundamentally about transferring responsibility for energy efficiency decisions from consumers to suppliers. As discussed above, many consumers do not have the tools to make rational decisions regarding energy efficiency, but utility and government DSM programs can reduce some of the cognitive barriers by using consumer financial incentives to promote more efficient levels of energy consumption and by supplying information about specific energy efficiency measures and their calculated effects.

Full and partial decoupling mechanisms tend to be politically feasible, partially because they require relatively low administrative cost. Unlike some alternative energy-efficiency promotion methods, decoupling mechanisms do not require regulators to evaluate the efficacy of energy efficiency programs. Furthermore, decoupling mechanisms reduce the need for frequent rate cases and avoid the associated costs (EPA 2007). The only public cost of a decoupling mechanism is the time it takes state employees to learn about the new system and establish proper regulations (CSI 2008).

Another reason for the political feasibility of decoupling mechanisms is their tendency to attain utility support. Utilities tend to support decoupling because it stabilizes their revenues and thus reduces their risks associated with revenue volatility. This decreases their costs of capital, both in terms of interest rates and equity returns required (Lazer, Weston, and Shirley 2011). In addition, utilities often prefer decoupling to traditional regulation because they believe that the traditional rate cases do not take all real-world factors into account in their predictions and calculations of rate requirements, leading to earnings that are lower than authorized earnings a few years after the rate case (Costello 2011).

Arguments Against the Implementation of Decoupling Mechanisms

Opponents of decoupling have voiced several concerns about decoupling mechanisms. They are skeptical about the efficacy of decoupling mechanisms in promoting energy efficiency. This section discusses the current debates surrounding these potential drawbacks of decoupling mechanisms and includes policy suggestions to mitigate these drawbacks, when applicable.

One category of critiques of decoupling mechanisms is that they fail to provide an incentive for energy efficiency investment. Many experts argue that, although decoupling mechanisms will eliminate the incentive to actively increase energy consumption, utilities will still fail to pursue energy efficiency because supply-side investments will continue to be more attractive to them than DSM investments (Kihm 2009). Historically, utilities have gained from supply-side investments because traditional rate setting has *de facto* allowed more than a normal rate of return on these investments. If investments in DSM do not provide comparable returns, for instance because they cause decreased future demand for utility service, it would presumably be more difficult for a utility to attract funding for DSM investments than for supply-side investments (EPA 2007).

Kihm (2009) argues that even if DSM performance incentives for utilities were large enough to provide comparable rates of return for DSM and supply-side investments, many utilities would continue to prefer supply-side investments because they are larger in scale. Utilities have historically preferred larger scale investments to smaller scale investments, a concept known as the Averch-Johnson (A-J) hypothesis. This preference often remains even with choices involving a large-scale investment with a lower rate of return than an alternative small-scale investment such as DSM investments. Kihm argues that decoupling only works for utilities not subject to the A-J effect, or utilities with allowed rates of return close to the cost of capital, and it is unlikely that most utilities fall into this category. Finally, utility managers and regulators have historically backed expansions in future electricity generation capacity because the risks to the utility of future inadequate electricity supplies are higher than the risk of having excess capacity. (Kihm 2009)

On the other hand, there are several reasons that a decoupled utility may prefer DSM investments to supply-side investments, even without the presence of performance incentives. From a customer service standpoint, DSM investments improve the public's view of the utility, enable more positive utility-customer interaction than supply-side investments, and generate less political opposition than supply-side investments. Supply-side investments usually involve building pollution-emitting power plants near specific communities, who may resist the project or request compensation for its undesirable effects (Bloomquist 1974). Conversely, DSM investments do not severely adversely impact a concentrated group of people; they usually substantially help a concentrated number of people – the customers who choose to participate in the DSM programs – at a minute cost to many (ECW 1997). As a result, DSM investments will often generate less political opposition than supply-side investments. The utility can even capitalize on this distribution of costs and benefits and improve its public ratings by publicizing the savings of the customers who benefit the most.

Moreover, with the uncertainty of the future energy regime, DSM investments may actually attract investment more than supply-side investments due to the relative effects on risk and energy security. Reduced energy consumption and decreased dependence on energy from out-of-state or oversea sources renders a utility less susceptible to unexpected future changes. These include unanticipated capital cost increases, increases in energy regulation stringency, transportation cost increases, and politically or economically-induced fossil fuel supply shortages. (Hurley et al. 2008, EPA 2007)

Opponents of decoupling are also skeptical of its efficacy in promoting energy efficiency because it creates a disincentive for consumer energy efficiency investments. They argue that decoupling mechanisms discourage customers to decrease electricity use because doing so will cause a future increase in electricity rates (Graniere and Cooley 1994). However, each individual's effect on the price is trivial. Thus, for the individual, decreased consumption outweighs any effect of their own behavior on rates (NARUC 2007). The monetary benefits of reducing consumption are very concentrated, while the corresponding costs from the associated rate increase are widespread. As a result, each customer not only has an incentive to reduce consumption, but also has an incentive to reduce consumption even more substantially than the other customers (ECW 1997).

Finally, decoupling mechanisms have limited efficacy because they fail to address some important causes of energy inefficiency. The principal-agent problem still exists in the presence of decoupling mechanisms since consumers who do not pay for their energy use still lack incentives to decrease this use under decoupling (Gillingham, Newell, and Palmer 2009). Similarly, the adoption of decoupling does not solve consumer choice failures and many consumers who would benefit from energy efficiency changes will not make those changes, whether or not their utility possesses a decoupling mechanism (Brennan 2008).

In addition, opponents of decoupling worry that the mechanism will increase the volatility of electricity rates and cause frequent, significant rate increases (Lesh 2009). Graniere and Cooley (1994) did a numerical study on this issue and concluded that, "ratepayers might have to deal with substantial volatility." On the other hand, Eto, Stoft, and Belden (1994) found that ERAM, California' decoupling mechanism, reduced rate volatility and had a negligible effect on rate levels. Similarly, Lesh (2009) found that decoupling adjustments tend to be very small relative to residential retail rates, with no significant upward or downward trend in rates. Compared to other adjustment factors on bills, such as fuel and purchased-power adjustment clauses, volume-balancing decoupling adjustments tend to alter rates less drastically (Lazer, Weston, and Shirley 2011).

Moreover, even if electricity rates do increase, there is a beneficial aspect to this in that it adjusts for the negative externalities on the environment. Michelfelder (1993) found that electricity rates are consistently below marginal social costs of producing electricity. Thus, increasing electricity prices actually brings them closer to the long-run marginal social cost of electricity production, which ultimately benefits ratepayers (Graniere and Cooley 1994). Furthermore, Bhole et al. (2011) found significant positive correlation between electricity prices and state energy efficiency expenditures, especially above a threshold price level. He proposed that higher electricity prices increase the cost-effectiveness of DSM programs. In addition, Linn (2008) contends that higher energy prices increase the probability that plants adopt new energy efficiency technologies, especially for new plants, although Kahn and Mansur (2011) suggest that new plants in energy-intensive industries would factor electricity prices into their location decision and specifically choose a geographical location where electricity prices were lower. The Center for State Innovation (2008) argues that, while decoupling mechanisms may increase energy costs for some customers in the short run, the diminished need for new power plants due to reduced energy demand will ultimately lower rates to all customers.

Opponents of decoupling are particularly concerned about decoupling mechanisms shifting weather and economic risks from utilities to consumers in the form of rate volatility (Meneken 2007). They argue that utilities bear none of the costs associated with extreme weather or economic recessions under decoupling. They point to Maine's brief experience with a decoupling mechanism as an example. Shortly after Central Maine Power adopted a full decoupling mechanism in 1991, Maine fell into a recession. Required revenues were too high, as they had been set based on a trial period during a thriving economy. Thus, prices increased drastically as energy consumption fell, and customers bore the full burden of the recession while Central Maine Power emerged unscathed. The decoupling mechanism was ultimately terminated due to animosity towards the mechanism produced by this incident. Many customers believed the true purpose of the mechanism was to shift risk from utilities to customers. (EPA 2007)

A report from the EPA (2007) contests that this risk shift is inherent to decoupling and argues that the existence and magnitude of this risk shift varies with the decoupling design. Lazer, Weston, and Shirley (2011) completely dismiss the argument that decoupling shifts weather risks to consumers under full and partial decoupling mechanisms and argue that decoupling decreases the risk for utilities *and* consumers. If an extreme weather event causes people to consume more electricity, decoupling causes rates to decrease, making the energy consumption more affordable for consumers. Lazer, Weston, and Shirley (2011) do admit that decoupling exacerbates effects of recessions, but they argue that general rate cases do so as well. They suggest combining decoupling with a cap on rate increases to prevent situations like the one that occurred in Maine.

Some opponents of decoupling may argue that decoupling is regressive. Low-income customers tend to have less electricity reduction potential than higher-income users. While they do not reap many of the benefits of reduced electricity use due to energy efficiency programs, they are still subject to the higher rates caused by the overall reduced demand (Lesh 2009). To address the potential concern of increased short run costs for low-income customers, most decoupled utilities offer lower rates to low-income customers and do funding and surcharging on a customer class, or rate schedule, basis (Lesh 2009).

Other concerns regarding decoupling include the lack of incentive for utilities to restore service after a storm and increased regulatory costs due to frequent true-ups. These are both founded yet not particularly compelling concerns. The first issue can easily be addressed through additional requirements or incentives in the design of the decoupling mechanism (Lazer, Weston, and Shirley 2011). Periodic true-ups do produce administrative and regulatory costs, but true-ups are less administratively costly than rate cases. The increased regulatory cost due to true-ups is offset to some degree by a reduction in the need for frequent rate cases and their associated costs (EPA 2007).

Brief History of Decoupling Adoption in the U.S.

Decoupling mechanisms have been operational in the United States since 1978, when Pacific Gas & Electric decoupled natural gas sales (AGA 2007). Four years later, PG&E also implemented a decoupling mechanism known as the Electric Rate Adjustment Mechanism (ERAM), for electricity sales (McCarthy 2009). Other Californian utilities adopted similar mechanisms shortly thereafter. In the early 1990's, Maine, New York, and Washington also adopted decoupling mechanisms, although Maine discontinued its mechanism after a brief trial period (Eto et al. 1994, EPA 2007). By September 2007, at least one natural gas or electric utility in 16 states had implemented a decoupling mechanism, and decoupling mechanisms were pending in 12 more states (EPA 2007). As of June 2011, utilities in about 28 states had adopted a decoupling mechanism, and decoupling mechanism implementation decisions were pending in 12 more states (Lazer, Weston, and Shirley 2011, ACEEE 2011).

Measuring the Effects of DSM and Decoupling on Energy Efficiency

There exists much debate in the literature about how to measure the efficacy of DSM programs. The true program effects cannot be measured by solely analyzing theobserved change in energy consumption of customers who participate in the DSM programs. On one hand, Joskow and Marron (1992) argue that savings of utility DSM programs tend to be overstated due to overly optimistic equipment lifetimes and the existence of *free riders*, or program participants who would have invested in energy efficiency even without utility involvement. On the other hand, many DSM program analysts worry about the opposite: understating the benefits of DSM programs. Program participants may discuss energy efficient behavior and technology with non-participants, who consequently decrease their energy use without any additional direct utility investment. For example, a customer might experience huge reductions in heating and cooling costs after using a utility rebate to add attic insulation in her home, rave about this experience to a friend who is not eligible for the rebate, and convince the friend to install attic insulation as well. These non-program participants are commonly referred to as *free drivers* (Gillingham et al. 2009). Due most likely to measurement differences, Parformak and Lave (1996) found that 99% of utility-reported estimates of savings from DSM are fairly accurate if one controls for price, weather, & economic activity, while Loughran and Kulick (2004) found that utility estimates of electricity savings due to DSM investment are much larger than the true savings. Gowever, Auffhammer et al.

(2008) pointed out flaws in Loughran and Kulick's methods. Thus, there is no consensus on the reliability of utility savings estimates from DSM.

The current literature lacks *ex post* empirical analysis that uses recent data to measure the effects of decoupling mechanisms on energy demand. Past studies on the impacts of decoupling mechanisms on energy demand have been almost exclusively based on *ex ante* economic modeling. Past studies of DSM programs, however, have included both *ex ante* economic modeling and *ex post* empirical studies of the impact of DSM programs on energy efficiency. Probably due to the uncertainties surrounding measuring savings from energy efficiency, there appears to be a discrepancy in demand reduction estimates between these *ex post* and *ex ante* studies. For example, studies of the cost-effectiveness of utility DSM programs that use *ex post* empirical analysis tend to find programs less cost-effective than those that rely primarily on *ex ante* methods (Arimura et al. 2011). In terms of research on the impact of decoupling mechanisms on energy efficiency, this suggests that results from *ex ante* models may differ significantly from the true effects. Thus, there is a need for *ex post* empirical studies on the impact of decoupling mechanisms on energy demand.

Factors that are commonly believed to affect residential electricity demand include DSM spending in current and previous years, economic activity level, energy prices, weather conditions, and environmental sensitivity, or the general level of concern of customers about the environment (Delmas et al. 2005, Arimura et al. 2011). Jaffe and Stavins (1995) developed a functional form for the relation between DSM spending and electricity demand that takes into account the nonlinear relation. Arimura et al. (2009) pointed out a possible endogeneity issue in models of electricity demand with DSM spending considered an exogenous variable. They were concerned that level of DSM spending may be correlated with unexplained fluctuations in demand. They attempted to use Two-Stage Least Squares (2SLS) estimation and instrument for DSM spending. However, their results do not support the hypothesis that DSM spending is endogenous (Arimura et al. 2011).

Arimura et al. (2011) conducted a fairly thorough analysis on the cost-effectiveness of electricity energy efficiency programs and some of its determinants, including decoupling mechanisms. The results of this study suggest that decoupling mechanisms may strengthen the demand-reducing effect of DSM spending. Unfortunately, due most likely to insufficient data from decoupled electric utilities, these findings were insignificant.

The present study aims to build on the previous literature and the methods of Arimura et al. (2011) to more thoroughly explore the relation between decoupling mechanisms and electricity demand. It first models the economic incentives behind DSM investment under traditional regulation and under a decoupling mechanism and then empirically analyzes the effects of decoupling mechanisms on energy consumption per customer. This study disregards the potential issue of endogeneity due to correlation of DSM spending with unexplained demand, as Arimura et al. (2011)'s results do not suggest that this issue of endogeneity exists. Finally, robustness checks are performed on the results of the empirical analyses.

Modeling DSM Investment Incentives

Introduction

The situation in which the regulator sets a required price or revenue for the utility and the utility decides how much and how effectively to invest in DSM programs can be represented as a principal-agent game. The regulator is the principal, and the utility is the agent. As in all principal-agent games, the principal has an objective function, but does not have all the information it needs to best maximize this function. The agent has the information necessary to better maximize this function, but it acts only in its own self-interest. Due to this asymmetric information, the principal needs the agent in order to reach its objective, but it runs the risk that the agent's objectives will differ from the optimal attainment of the principal's objective. The regulator must design the game in such a way that the incentives of the two parties align.

In this game, the regulator (principal) wants to maximize a social welfare function, while the utility (agent) is only concerned with its profits. The utility has more information than the regulator does about the DSM options available and about the projected efficacy of each option. The utility can use this information asymmetry to increase its profits by acting strategically.

In a simple version of a principal-agent game on DSM program investment under traditional regulation, the regulator wants to maximize social welfare. Social welfare is defined as the integral of demand, or marginal social benefit of consuming one unit of electricity, less the marginal social cost of producing and consuming that electricity. It is a function of the exogenous, regulator-determined price (p), quantity of electricity consumed (q), and the marginal net social benefit electricity consumption schedule. It is assumed that marginal social cost of electricity consumption is greater than marginal private cost, since the GHG emissions, air pollution, and other environmental costs associated with electricity are not internalized in the private cost of electricity. For the same reasons, it is also assumed that the quantity of electricity consumed is above the efficient quantity. The regulator, therefore, wants to decrease quantity of electricity sold by encouraging DSM spending. The regulator can do so by:

A. Requiring $***X*** of DSM spending
B. Adjusting the rate of return on investment via a specific price (***p***) or revenue (***R***) based on the utility's reported DSM spending in the previous period

or

C. Adjusting the rate of return on investment via a specific ***p*** or ***R*** based on perceived DSM investment efficacy.

For the purpose of this exercise, it is assumed that the regulator can choose one of two allowed rates of return, a high reward rate (associated with $\boldsymbol{p_H}$ or $\boldsymbol{R_H}$) and a low punishment rate (associated with $\boldsymbol{p_L}$ or $\boldsymbol{R_L}$). Strategy (B) assumes that the reward price is set if the utility invests at least $**X** in DSM and that the punishment price is set otherwise. Strategy (C) assumes that the regulator uses electricity consumption in the previous period (i.e. since the last rate case) to determine which $\boldsymbol{p}$ (or $\boldsymbol{R}$) to set in the current period. For any given period, the regulator can try to encourage the utility to invest in DSM by promising to set its price in a future period $\boldsymbol{p_{t+1}}$ (or $\boldsymbol{R_{t+1}}$) as a function of estimated demand-reducing effect of DSM investment in the previous period. The value of this demand reduction due to DSM is henceforth denoted $\boldsymbol{E_{DSM}}$.

Under strategy (C), while the regulator cannot precisely measure the efficacy of a DSM program relative to other potential programs, it can estimate the efficacy by observing energy consumption per capita. The regulator can examine market trends and relevant factors to estimate projected consumption, $\boldsymbol{q_{p,t}}$ in the given period. It cannot confidently attribute changes in realized demand to DSM investment or lack thereof; yet it knows that actual energy consumption ($\boldsymbol{q_{a,t}}$) equals $\boldsymbol{q_{p,t} - E_{DSMt} + \varepsilon_t}$, where $\boldsymbol{\varepsilon_t}$ captures unexpected variation and has mean zero. The regulator can, therefore, set price ($\boldsymbol{p_{t+1}}$) or revenue ($\boldsymbol{R_{t+1}}$) in the next period as a function of $\boldsymbol{q_{p,t} - q_{a,t}}$ so as to alter projected revenues for period t+1 as a result of actual quantity of electricity consumed in the previous period ($\boldsymbol{dp_{t+1}\, q_{t+1}/dq_{a,t}}<0$). For simplicity, it is assumed that the regulator determines a cutoff $\boldsymbol{q_{c,,t}}$ such that $\boldsymbol{q_{c,,t}} \leq \boldsymbol{q_{c,,t}}$. For any given period $\boldsymbol{t}$, the regulator sets the rate as $\boldsymbol{p_{H,t}}$ or $\boldsymbol{R_{H,t}}$ if the previous period resulted in a $\boldsymbol{q_{a,t-1} \leq q_{c,t-1}}$ and sets the rate as $\boldsymbol{p_{L,t}}$ or $\boldsymbol{R_{L,t}}$ otherwise. When the regulator chooses to set prices, it sets the rates based on projected revenues and associated quantities ($\boldsymbol{q_H}$ and $\boldsymbol{q_L}$ respectively), such that $\boldsymbol{p_H\, q_H > p_L q_L}$. Thus, the regulator takes the demand-reducing effect of DSM into account when setting these rates.

This is a credible strategy for some reward rate ($\boldsymbol{p_H}$ or $\boldsymbol{R_H}$), punishment rate ($\boldsymbol{p_L}$ or $\boldsymbol{R_L}$), and $\boldsymbol{q_c}$ because the prospect of increased future consumer surplus due to decreased consumption outweighs the potential decrease in consumer surplus as a result of a higher price, for some sufficiently-large consumption reduction and some sufficiently-small price increase. Note that this model does not attempt to uncover the specific value of $\boldsymbol{X}$, the reward rate, the punishment rate, or the $\boldsymbol{q_c}$. It simply demonstrates the differences in effects of regulator- or third party-imposed DSM standards and incentives on utility DSM investment under traditional regulation versus decoupling mechanisms.

Part A – Traditional Regulation

Under traditional regulation, the utility's objective function is denoted:

$$\text{Max } \pi_t = \underline{p_t q_t} - f_t - S_t$$

where f_t is the fixed costs associated with supplying electricity to the current customers and S_t is the amount that the utility spends on DSM in period t. Note that this model assumes no marginal costs of electricity distribution. For any given p, set by the regulator, the utility wants to maximize q. The first order derivative of the above equation with respect to DSM spending is the following:

$$\frac{d\pi_i}{dS_i} = p\frac{dq_i}{dS_i} - 1$$

with $dq_t/dS_t \equiv E_{DSMt} < 0$.

If the regulator does not institute any rules or incentives concerning DSM and sets prices exogenously, it is evident from the above equation that the utility will maximize q and will not invest in DSM at all. If the regulator chooses strategy (A) and requires the utility to spend $**X** on DSM, the utility has an incentive to steer away from effective DSM programs. The utility would prefer to burn the money than spend it on DSM. Similarly, if the regulator chooses strategy (B) and bases prices on the amount of DSM spending in the previous period, the utility has an incentive to spend $\$X$ on DSM if the present value of the benefits of doing so is greater than the costs, but it will choose to do so as ineffectively as possible. If the utility can spend $\$X$ on DSM without actually affecting energy consumption at all ($dQ/dS=0$), it will choose to do so if $\delta(p_H q_H - p_L q_L) > X$ where δ is the utility's discount factor ($0 \leq \delta \leq 1$).

The utility must be bribed or punished more if the DSM spending were unavoidably slightly effective.

If the regulator uses signals other than spending to estimate the utility's effective investment in DSM and sets prices accordingly (strategy C), the utility will effectively[3] invest an amount, **X**, in DSM in a given period if the present value of the benefits of this investment is greater than the associated cost. This is represented by the following inequality:

$$[\theta_1(p_H q_H) + (1-\theta_1)(p_L q_L) - \theta_2(p_L q_L) - (1-\theta_2)(p_H q_H)]*\delta \geq X + p_t*E_{DSM,t}$$

where θ_1 is the probability of low demand being realized ($q_a < q_c$) if the utility invests $\$X$ in DSM, θ_2 is the probability of high demand being realized ($q_a > q_c$) if the utility does not invest in DSM, , and p_t is the price in the current period.

Assuming that the expected value of q_a is greater if the utility does not invest than if it does, (i.e. $\theta_1+\theta_2>1$), this inequality can be rearranged to the following:

$$(p_H q_H - p_L q_L) \geq [X + p_t E_{DSM,t}]*[1/(\delta(\theta_1+\theta_2-1))]$$

The utility will only effectively invest $\$X$ in energy efficiency if the punishment price is associated with a revenue sufficiently less than the revenue associated with the reward price. The sufficient difference decreases if the direct cost of the DSM investment decreases, if the price in the current period is smaller, if the expected demand-reducing efficacy of the investment is smaller, if the utility values the future relatively more (δ is greater), or if the probability of the demand realization correctly reflecting the utility's actions is greater (i.e. the variability of ε is lower).

[3] For simplicity, efficacy is constrained here to taking one value (1) if the investment is effective and 0 otherwise.

Part B – Decoupling

Under a full decoupling mechanism, the regulator chooses the utility's required revenue (R). The utility still chooses whether to invest in DSM and whether to do so effectively. In this case, however, the utility's profit is only a function of required revenues (and any changes in fixed costs). Any short-term excess or shortage of revenue is quickly offset by price true-ups in the next period. The utility's objective function is represented as:

$$\text{Max } \pi = \boldsymbol{R} - \boldsymbol{f} - \boldsymbol{S}$$

Note that quantity of energy sold does not influence the utility's profits adversely or favorably (dR/dS=0).

With no regulations or incentives for DSM investment, the decoupled utility has an incentive not to invest in DSM ($d\pi/dS$=-1). If the regulator chooses strategy (A) and requires the utility to spend \$$X$ on DSM, the utility is indifferent to efficacy of the investment. Similarly, if the regulator offers a higher allowed revenue if the utility spends at least \$$X$ in DSM (B), the utility will do so if the present value of the benefits outweighs the costs, $\delta(R_H-R_L)>S$, and will again be indifferent to the efficacy of the investment. The utility has no private incentive to invest more than the required amount in either of these cases.

The regulator can try strategy (C) and encourage the utility to invest in DSM in a repeated game by setting a required revenue each period, R_H or R_L (with $R_H>R_L$), as a function of actual energy consumption q_a in the previous period. The utility will choose to efficiently invest \$$X$ in DSM if and only if the present value of the benefits of investing \$$X$ in DSM outweigh the costs. In the case of a decoupled utility, this situation is represented by the following inequality:

$$[\theta_1(R_H) + (1-\theta_1)(R_L) - \theta_2(R_L) - (1-\theta_2)(R_H)]^*\delta \geq X$$

where ***δ, θ₁,*** and ***θ₂*** are specified as they were in part A. Under a decoupling mechanism, the utility experiences no cost of decreased consumption due to DSM investment. Assuming the expected value of q_a is lower if the utility invests in DSM, the situation adheres to the above inequality if and only if:

$$(R_H - R_L) \geq X^*[1/(\delta(\theta_1+\theta_2-1))]$$

The only factors that determine whether or not the utility will invest $**X** in DSM are the relative effects of doing so on future revenues, the utility's discount factor, and the probability of the regulator correctly assessing the utility's actions. Once again, the more the regulator wants the utility to invest in DSM, the larger the reward revenue must be relative to the punishment revenue. This revenue disparity can be smaller if the utility values the future relatively more or if the variance of ε is low.

Conclusions

Comparing Parts (A) and (B) suggests the following conclusions about the relative levels and efficacies of DSM investment under decoupling mechanisms and traditional regulation in the specified scenarios:

1. With no regulator incentives or standards, neither decoupled nor traditionally regulated utilities will invest in DSM
2. With regulator standards on required DSM spending, decoupled utilities will invest more effectively in DSM than traditionally regulated utilities
3. With regulator incentives based on amount of DSM spending only, decoupled utilities will be more likely to invest in DSM and will do so more effectively than traditionally regulated utilities
4. With regulator incentives based on perceived DSM investment efficacy as inferred from energy demand, decoupled utilities will produce more effective DSM investment than traditionally regulated utilities

The first three conclusions have been previously discussed, but the fourth is not immediately apparent. Under strategy (C), the regulator must offer a larger reward/punishment discrepancy to a utility that is regulated traditionally than it must offer to a decoupled utility in order to encourage the same amount of effective DSM investment. This is apparent by comparing the inequalities that represent the sufficient conditions for regular utility investment $*X* in DSM under each type of regulation. Since $p_H q_H$ is essentially analogous to allowed revenues, R_H, the sufficient condition is:

$$(R_H - R_L) > [X + p_0 E_{DSM}]*[1/(\delta(\theta_1+\theta_2-1))]$$

under traditional regulation. Under a full decoupling mechanism, the sufficient condition is:

$$(R_H - R_L) \geq X * [1/(\delta(\theta_1+\theta_2-1))]$$

Since p_H and E_{DSM} take only positive values, it is evident that:

$$[X + p_0 E_{DSM}]*[1/(\delta(\theta_1+\theta_2 -1))] > X * [1/(\delta(\theta_1+\theta_2-1))]$$

Thus, the sufficient reward/punishment structure to encourage DSM investment of $*X* is greater under traditional regulation than under a decoupling mechanism. Furthermore, it is reasonable to assume that increasing $R_H - R_L$ is costly for the regulator, as it is bounded by a minimum revenue that will cause the utility to shut down and would cause decreased consumer surplus due to higher energy prices on the other extreme. As a result, regulators will probably not offer reward/ punishment structures that incentivize comparable DSM investments under the two types of regulation. The reward/punishment structure associated with the decoupled utility will probably induce more DSM investment. Thus, utilities will probably invest more in DSM under decoupling than under traditional regulation.

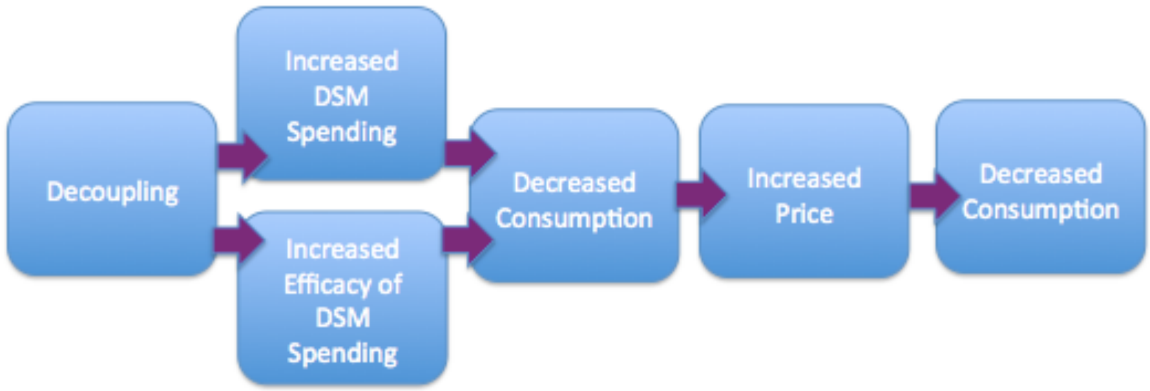
It is important to note that this model is not a perfect representation of the interactions between utilities and regulators concerning DSM investment. Furthermore, these incentive models only compare incentives under decoupling mechanisms to those under traditional regulation. Utilities under regulation types that are neither traditional regulation nor decoupling mechanisms may possess different incentives than traditionally regulated or decoupled utilities. Nonetheless, this paper cautiously extends the implications of this model to form hypotheses about how decoupling mechanisms affect utility DSM investments and electricity consumption compared generally to all other utilities.

Theory and Methods

Hypotheses to be Tested

The previous models suggest that the effect of decoupling on DSM can be broken down into at least two effects: its effect on the level of DSM expenditure and its effect on the efficacy of DSM expenditure, given a fixed level of investment. According to the models, each of the two effects should reduce energy consumption if decoupling is combined with DSM incentives or energy-efficiency standards. Furthermore, under decoupling mechanisms, reduced consumption inherently affects price. Combining this with downward-sloping demand produces a third pathway by which decoupling and DSM reduce demand.

Therefore, this study investigates the hypothesis that decoupling mechanisms decrease residential electricity consumption, but only through their effect on the level, direct demand-reducing effects, and indirect demand-reducing effects through price of DSM investment. This hypothesis is represented graphically below:



Specifically, to test this overall hypothesis, this paper explores the following subordinate hypotheses:

1. Decoupling mechanisms only affect residential electricity consumption and retail price through their effects on DSM investment.
2. Decoupling mechanisms are associated with increased utility DSM expenditure.

3. Decoupling mechanisms increase the direct demand-reducing effect of residential DSM programs.

4. Decoupling mechanisms increase the efficacy of DSM investment through the indirect effect of DSM on consumption through price.

Analyses of these subordinate hypotheses allow for a better understanding of the nature and potential magnitudes of the effects of decoupling mechanisms on energy efficiency. Due to the limited timeframe of the data, only very short-term realizations of these hypotheses can be analyzed in this study. As discussed later, however, it is reasonable to believe very short run effects (1-4 yrs) will indeed translate into slightly longer-term effects (≈5-10 yrs).

Data and Methods

This paper builds on previous analyses of energy efficiency and DSM investment to model the effects of decoupling mechanisms on electricity consumption. Loughran and Kulick (2004) conducted a time-series cross-section/time-series analysis on the effect of DSM investment on electricity consumption, and Arimura et al. (2011) similarly modeled the cost-effectiveness of electricity energy efficiency programs. Contrary to these previous studies, the present paper includes post-2006 data[4], recognizes the endogeneity issues of including utility-level electricity prices as a right-hand-side variable, and includes a vector of time fixed effects to better control for national time trends and structural breaks in electricity consumption.

Due to discrepancies in frequency of reporting in EIA forms, two primary data sets were assembled for this analysis: one with monthly observations and one with annual observations. The former is used for the majority of the analysis, while the latter is used for analyzing the second subordinate hypothesis – the effect of decoupling mechanisms on level of DSM spending – only. The entire study focuses on the residential sector and uses data from January 2001 to December 2010.

For the monthly data set, data on monthly electricity consumption by sector for each US electric utility were retrieved from the Energy Information Administration database (Form EIA-826). These data were combined with annual customer data by sector for each utility (Form EIA-861) to obtain electricity consumption per customer by sector for each utility. Utilities that serve customers in multiple states were separated into multiple utilities, one per state, because utility decoupling regulation laws vary by state.

Four hundred four utilities, each with 50-120 monthly observations, were included in the analyses on monthly data. Seventy utilities with fewer than 50

[4] The vast majority of decoupled US utilities did so post-2006.

months of data were excluded from the monthly analysis. Extreme observations, or consumption observations that varied from the prior month by a factor of five or greater were examined and altered or excluded from the data, as appropriate. These observations are likely results of mergers or acquisitions, temporary utility shutdowns, human error in reporting, or natural disasters such as hurricane Katrina. In the case of supposed mergers or acquisitions, utilities were labeled as multiple, unique utilities before and after the event. A few observations that portrayed negative sales were also discarded from the analysis. In total, eleven observations were discarded due to negative sales or suspicion of utility shutdowns, human error, or natural disasters.

DSM spending data is only available on the annual level from Form EIA-861. Therefore, an annual data set was created to analyze DSM spending. In this analysis, utilities with fewer than five years of data were discarded. Data from utilities that resided in multiple states were also excluded from the analysis since distinguishing between spending in each state was not feasible for these utilities. It is notable that many utilities are completely excluded from Form EIA-861. Only 161 utilities and 1,502 annual observations were included in this part of the analysis, primarily due to lack of DSM spending data.

Some third-party DSM spending through utilities is also reported by utilities on EIA Form 861. As shown in the literature, this is reasonable, as the existence of a decoupling mechanism affects a third-party energy efficiency provider ‘s ability to effectively invest in DSM (Lazer, Weston, and Shirley 2011). The inclusion of ratepayer-funded “third-party” DSM spending reduces bias resulting from the geographical heterogeneity in structure and existence of regulatory institutions responsible for promoting DSM.

This paper replicates many of the control variables and uses several of the data sources from previous studies. As a departure from some of the previous literature, this paper controls for the existence of a state energy efficiency resource standard (EERS), state quarterly personal income, and time fixed effects.[5]

OLS and 2SLS cross-section/time-series analyses are used to investigate the stated hypotheses. First, the effect of a decoupling mechanism on residential, per-customer electricity consumption is first estimated using the following OLS model:

Equation 1:

$$Elect_{usmt} = B_0 + B_1Decoupling_{usmt} + B_2Res.Customers_{ust} + B_3NatGasPrice_{smt} + B_4FuelOilPrice_{mt} + B_5GDP_{st} + B_6Pop_{st} + B_7Income_{st} + B_8EERS_{st} + B_9EnvSensitivity_{st} + B_{10}CDD_{smt} + B_{11}HDD_{smt} + \alpha_u + \gamma_{sm} + \varepsilon_{usmt}$$

where Elect = the natural logarithm of residential, per-customer electricity consumption, EERS = a dummy variable for whether or not the state had an Energy Efficiency Resource Standard in place, EnvSensitivity = an state environmental sensitivity measure, CDD = cooling degree days , HDD = heating degree days, u = utility, s = state, m = month, and t = year. α and γ are vectors of utility-level and time fixed effects, respectively. See Appendix B for full descriptions of the variables. The natural logarithm of residential electricity consumption is used as a dependent variable to capture percentage, as opposed to absolute, changes in consumption.

By including a vector of utility-level fixed effects, or a dummy indicator variable for each utility, the analysis controls for all systematic differences between utilities, such as size, that do not vary within the decade. The inclusion of a vector of time fixed effects normalizes out any nationwide time trends and time-specific changes that would affect the dependent variable. Utility customer base and state- and time-specific indicators of weather, economic growth, population growth,

---

[5] In contrast to Arimura et al.'s study, this paper does not attempt to model the relation between building codes, housing starts, and energy consumption. Arimura et al. neglect to account for the time lag in importance of building codes. Without a mechanism to capture this complicated relation, these variables seem to pick up other political and environmental sensitivity factors and may actually confound results.

income, environmental standards, and demonstrated environmental concern are exogenous control variables. With all of these controls, the only remaining variation for the existence of decoupling and other potential omitted variables to explain is utility-specific changes in consumption per customer over time that are not a result of changes in size of the customers base.

The full model of the effect of decoupling mechanisms on residential, per-customer electricity consumption includes DSM spending and an interaction between DSM spending and the decoupling dummy variable. This 2SLS model also controls for an instrumented utility-level retail electricity price:

Equation 2:

$$Elect_{usmt} = B_0 + B_1 Decoupling_{usmt} + B_2 Res.Customers_{ust} + B_3 ElectricityPrice_{mt} + B_4 NatGasPrice_{smt} + B_5 FuelOilPrice_{mt} + B_6 GDP_{st} + B_7 Pop_{st} + B_8 Income_{st} + B_9 EERS_{st} + B_{10} EnvSensitivity_{st} + B_{11} CDD_{smt} + B_{12} HDD_{smt} + B_{13} DSM_{ust} + B_{14} DecouplingxDSM_{usmt} + \alpha_u + \gamma_{sm} + \varepsilon_{usmt}$$

with all terms defined as they were in the previous model. In the *Robustness Tests* section, this study explores the potential issue of endogeneity of decoupling in this equation.

Despite the research of Jaffe and Stavins (1995) regarding the lingering effects of DSM investment on consumption, this analysis finds that a linear relationship between the logarithms of this year's DSM investment and consumption is the best-fitting model of the relation between recent DSM investment and this year's consumption. Lagged values of DSM investment are not significant.

To address the endogeneity of electricity price through 2SLS, 2005 state-level data on the percent of electricity generation from oil, natural gas, and coal are interacted with monthly city gate (wholesale) natural gas price, monthly US oil refiner costs, and the average annual price of coal, respectively. State-level percent generation from renewable sources is also interacted with US coal price[6]. There is no reason to believe that these variables would impact electricity demand except through their effect on electricity price and potentially through their effect on retail natural gas price. A test of joint significance on the coefficients of these instruments in the first-stage regression produces an F-statistic of 45.8, which is associated with a p-value of less than .0001. This confirms the validity of these instruments.

The following cross-section/time-series model of total utility annual DSM spending per residential customer is used to explore the effect of decoupling on level of DSM spending:

Equation 3:

$$DSM_{ust} = B_0 + B_1 Decoupling_{ust} + B_2 Res.Customers_{ust} + B_3 GDP_{st} + B_4 Pop_{st} + B_5 Income_{st} + B_6 EERS_{st} + B_7 EnvSensitivity_{st} + B_8 CDD_{st} + B_9 HDD_{st} + \alpha_u + \gamma_t + \varepsilon_{ust}$$

where DSM = the natural logarithm of annual DSM spending, u = utility, s = state, and t = year. α and γ are vectors of utility-level and time fixed effects, respectively.

Standard errors, clustered on utility, were used in all regressions to account for heteroskedasticity and autocorrelation. Even when a vector of time fixed effects is included, a Woodridge test for autocorrelation in panel data generated an $F(1,403)$ statistic of 355, which is associated with a less than .1% chance that the data does not suffer from autocorrelation. The clustered standard errors are much more robust to issues of autocorrelation and heteroskedasticity than the traditional standard errors. The true autocorrelation structure of the data could not be captured, so this approach is the best available option. Note that the presence of autocorrelation solely affects the predicted standard errors of point estimates, while inaccurate efforts to capture the autocorrelation structure would cause endogeneity issues and bias the point estimates.

[6] Interaction terms between percent renewable generation and other fuel prices as well as the interaction between monthly uranium price and percent generation from nuclear energy were excluded because they were found to be irrelevant in the first stage.

Results

Overall Effects of Decoupling on Consumption and Price

Consistent with subordinate hypothesis #1, this section shows that decoupling mechanisms are correlated with electricity consumption and price only through their relation with DSM investment. These findings are robust to exclusion of the environmental sensitivity indicator variable and the dummy variable of existence of a state energy efficiency resource standard.

The first model (Equation 1) includes decoupling but not price, DSM or its interaction with DSM. Thus, the coefficient on decoupling in this model can be understood as the full effect of DSM through its various channels. As Column 1 of Table 1 indicates (See Appendix A), the coefficient of decoupling (B_1) in this model is -.05. This coefficient represents the difference in the expected means of the natural logarithm of consumption between decoupled utilities and non-decoupled utilities. Alternatively, the ratio of the mean of consumption for decoupled utilities over non-decoupled utilities is $e^{-.05}$, or about .95. All else equal, if a utility switches to having a decoupling mechanism from having none, expected residential, per-customer electricity consumption decreases by about 5%. The sign of this result is significant at the 2% level for a test of the null hypothesis that decoupling mechanisms has no effect on residential electricity consumption.

When the effects of decoupling on consumption working through price and DSM investment are eliminated, however, this significance disappears. To test the effects of eliminating these potential causal avenues, Equation 2 (Column 2 Table 1 – Appendix A) adds as controls residential electricity price, utility log annual DSM spending, and an interaction term of DSM spending and a dummy for a decoupling mechanism to the model described by Equation 1. Because electricity price may be endogenous, this equation was estimated with 2SLS. The first stage regression is given in Column 1 of Table 3 (Appendix A).

With the inclusion of these variables, the coefficient on the decoupling dummy shrinks to -.007 and is not significantly different from zero. Since the model controls for level of DSM investment and for the increased demand-reducing effects of DSM investment associated with decoupled utilities, this coefficient estimates the effect of decoupling mechanisms not related to DSM investment or price on electricity demand. For decoupled utilities that do not participate in any DSM investment, the model finds no significant effect of having decoupled on electricity consumption.

This result is robust to exclusion of the environmental sensitivity rating variable and the variable for existence of an energy efficiency resource standard (Column 3 Table 1). Because environmental sensitivity ratings and the existence of an energy efficiency resource standard are correlated with the presence of a decoupling mechanism (r=.26 and .30, respectively), one might be concerned with the presence of these controls in the model. When these variables are excluded from the analysis, decoupling still shows no significant relation to consumption other than through its effect on DSM investment and price. The point estimate and 95% confidence interval on the isolated decoupling coefficient barely change.

Consistent with the literature and contrary to the fear of many opponents of decoupling, decoupling mechanisms alone do not appear to inherently significantly increase prices. Column 2 of Table 3 reruns the first stage analysis without the variables of DSM investment and its interaction with decoupling. Without holding these variables constant, decoupling does appear to increase prices. Specifically, decoupling is associated with a 1% increase in price when DSM investment is ignored, and this relation is significant at the 10% level.

If the effects of DSM investment are properly accounted for, however, these results disappear (Column 1 Table 3 – Appendix A). Holding DSM investment constant, if a utility has a decoupling mechanism but no DSM investment, the decoupling mechanism is predicted to have no significant effect on price. The coefficient on decoupling is .004 and is not significant at any conventional level. This insignificance remains when the environmental sensitivity and EERS control variables are excluded (Column 3 – Table 3). Therefore, this study concludes that decoupling mechanisms only affect price through their effect on DSM spending.

The striking difference in magnitude and significance of the coefficient associated with decoupling between models of electricity consumption that include DSM spending and those that do not is explored in the following sections.

Effect of Decoupling Mechanisms on Level of DSM Spending

To provide more insight into the relation between decoupling mechanisms and electricity consumption, this study analyzes three potential impacts that decoupling mechanisms may have on DSM investment. This section investigates the second subordinate hypothesis: the effect of decoupling mechanisms on the level of DSM spending. Contrary to the hypothesis, an estimate of the OLS model of DSM spending outlined in Equation 3 (Column 1 Table 2 – Appendix A) suggests that decoupling and level of DSM spending are not significantly correlated.

Because it is impossible to engage in negative DSM spending and because there are many utilities with $0 DSM spending, a tobit model may be more appropriate than an OLS model in this instance. Even with this model specification, however, the coefficient on decoupling is not statistically different than zero (Column 2 Table 2 – Appendix A). This provides further evidence that decoupling mechanisms and level of DSM spending are uncorrelated.

It is important, however, to consider the distribution of DSM spending. The distribution is not normal and has a skewness of 6.99. There are many observations with zero or very low values of DSM spending and a few observations with very extreme high values. To avoid assuming a normal distribution and to limit the effects of outliers, a quantile regression was used. The results of this model show a positive effect of decoupling on level of utility DSM investment that is significant at the 10% level (Column 2 Table 2 - Appendix A). This regression suggests that decoupling *does* encourage higher utility DSM spending and that the normal distributional assumption may have caused inaccurate estimates in the OLS and tobit models. The quantile model estimates that, all else equal, the possession of a decoupling mechanism increases a utility's predicted DSM spending by 41%.

Because of the failure of the quantile model to control for heteroskedasticity and autocorrelation[7], however, caution should be exercised when interpreting the significance of these results. Furthermore, recall that since DSM investment data is only available annually, this analysis has far fewer observations than the analysis of Equation 1. As there may be some bias due to the relatively small sample size of this dataset, this is another reason that the point estimate given by this model should be treated with caution.

Effect of Decoupling Mechanisms on the Direct Demand-Reducing Effects of DSM Spending

The third subordinate hypothesis in this paper is that, controlling for the level of DSM investment, decoupling mechanisms increase the demand-reducing effects of DSM spending. To test this hypothesis, the 2SLS model of Equation 2 (Column 2 Table 1 – Appendix A) is again used. This model controls for level of DSM investment and for the interaction between decoupling and DSM investment. The coefficient on this interaction term represents the increase in efficacy of DSM investment associated with decoupling mechanisms. This coefficient is estimated to be -.004 and is significant at the 5% level. This supports the hypothesis that decoupling mechanisms increase demand-reducing effect of utility DSM investment for a given level of investment. Given a fixed level of initial DSM investment, this model estimates that a 10% increase in DSM investment of a decoupled utility decreases estimated residential, per-customer electricity consumption by .04% more than a 10% increase in DSM investment of a non-decoupled utility would decrease estimated consumption.

[7] Due to insufficient observations clustered standard errors could not be computed in this part of the analysis.

Effect of Decoupling Mechanisms on the Efficacy of DSM Investment due to its Indirect Effect on Consumption Through Price

Besides increasing the demand-reducing effects of DSM investment, decoupling mechanisms may also increase the efficacy of DSM investment at reducing consumption through the effect of DSM investment on price. In utilities with decoupling, DSM investment is predicted to increase prices, and higher prices are predicted to decrease consumption (Hypothesis 4). This section explores this subordinate hypothesis by considering the estimation of the effect of DSM investment of decoupled utilities on price, contrasting this effect with that of non-decoupled utilities that invest in DSM, and verifying the predicted effect of increased prices on consumption.

As predicted, results suggest that DSM investment increases residential electricity price under decoupling mechanisms and has no effect on price under other types of regulation. In the first stage of the 2SLS model depicted in Equation 2, the coefficient on the variable depicting DSM investment is essentially zero and associated with a t-statistic of .17 (Column 1 Table 3 – Appendix A). This indicates that, for non-decoupled utilities, DSM investment does not significantly affect price. Among only decoupled utilities, however, there does appear to be a positive relation between DSM investment and price. The interaction term between decoupling and DSM investment (Column 1 Table 3 – Appendix A) is positive and significant at the 10% level. This weakly supports the hypothesis that DSM investment increases residential electricity price, at least in the short run, under decoupling mechanisms.

Consistent with economic theory, this study also finds evidence that higher prices decrease electricity demand. The coefficient on price in the second stage of this 2SLS model is -1.47, which is statistically significant at the .001 level (Column 2 Table 1 – Appendix A). A price increase of $.01/kWh is associated with a 1.5% decrease in demand. At a mean price of about $.10/kWh, this implies a price elasticity of about .15, which is within the -2.001 to -.004 range (median=-.28) of recent price elasticity estimates of short run demand in the literature (Espey and Espey 2004).

Robustness Tests

This section addresses some potential concerns about the estimates in Table 1. It first tests the sensitivity of the results to including a monthly rather than annual coal price as an instrumental variable to predict electricity retail price. It then explores whether the correlation between possession of a decoupling mechanisms and electricity consumption is partially due to the continuation of pre-existing trends. Finally, this section uses probit analysis to explore the possibility that electricity consumption affects a utility's decision to decouple and discusses the potential bias caused by the presence of this endogeneity issue.

Use of an Annual Instrumental Variable

Some readers may find the use of annual coal price as opposed to monthly coal price as an instrument for monthly electricity price troubling. Specifically, they may worry that the use of a replicated annual variable might artificially increase the power, or the perceived relevance, of the instruments. Monthly US coal prices were not available. To check the robustness of the annual US coal price estimate, models were estimated using a monthly coal price index, Australian thermal coal, in place of annual US coal price. This monthly index is found to be highly correlated with US coal price, but it is found to be an inferior instrument because it is slightly less powerful in explaining US retail electricity prices.

The replacement does not alter the rejection of the null hypothesis that the instruments are relevant. It does lower the 95% interval for the second stage effects of a $.01 increase electricity retail price on electricity consumption, from a decrease of between .6% and 2.3% to a decrease of between .2% and 1.7%. When both coal price indicators are included, the effect of the Australian coal price index on residential electricity price loses significance, and the 95% confidence interval of the decrease in consumption associated with a $.01 price increase becomes .4% to .9%. While the differences in these intervals are nontrivial, the overlap of the confidence intervals is notable. Furthermore, the use of the monthly indicator variable instead of the annual US price variable has a negligible effect on the point estimates and significance of the other exogenous variables. This provides evidence for robustness of the analyses in this study to a theoretical change in annual versus monthly US coal price.

Pre-Existing Trends

Because of the time-series nature of the data, it is important to consider the possibility that per customer electricity consumption was decreasing pre-decoupling for the utilities that later decoupled. Because all of the utilities in the data set that decoupled between the years of 2001 and 2010 did so after 2005, pre-existing trends can be captured by analyzing data from 2001-2005. Utilities that adopted decoupling mechanisms prior to 2001 were excluded from this part of the analysis.

Column 4 of Table 1 (See Appendix A) shows the estimation of a model using only 2001-2005 data of residential per-customer electricity consumption on a year trend, an interaction term between a year time trend[8] and whether the utility decoupled between 2006 and 2010, control variables, and utility-fixed effects. The interaction time trend should capture any systematic differences in energy use trends between utilities that later adopted decoupling mechanisms and those that did not do so. If per-customer energy consumption decreased relatively more or increased relatively less in utilities that later decoupled, the coefficient of this variable should be negative. In fact, as seen in Column 4 of Table 1, the coefficient of this interaction term is actually positive and significant at the 1% level. Controlling for the variables in the previous model, pre-2006 energy consumption was actually increasing more for utilities that decoupled during 2006-2010 than for utilities that did not decouple during this time period. Thus, the perceived effects of decoupling mechanisms reducing energy consumption do not seem to simply be the continuation of pre-existing utility-specific trends.

---

[8] Note – this year time trend is not used in models with time fixed effects due to its insignificance.

Potential Endogeneity of the Decoupling Variable

The upward trend in consumption for utilities that later decoupled suggests that increases in demand might have caused the adoption of decoupling mechanisms. In response to this concern, this study uses probit analysis to investigate what causes utilities to decouple. Column 1 of Table 4 (Appendix A) shows the results of a model that predicts whether a utility decoupled between 2006 and 2010 as a function of January 2001 values of various independent variables for the 384 utilities who had not decoupled by 2006. These results indicate that utilities with a lot of customers who each use a lot of energy that are located in wealthy, environmentally-conscious states are most likely to decouple. Controlling for these January 2001 characteristics, the results in Column 2 of Table 4 estimate how trends in variables between January 2001 and December 2005 affected utilities' decisions to decouple. These results suggest that the only 2001-2005 trend that is significant in predicting decoupling adoption was the institution of a state energy efficiency resource standard.

Furthermore, the t-statistic associated with the increase in energy use per customer is about 1, which suggests that, if anything, growing energy use per customer may also increase the chances of a utility decoupling, although this relation is not statistically significant. This finding is not simply due to multicollinearity between trend variables. The sign and the insignificance of the coefficient persists when per customer consumption is the only time trend included (Column 3 Table 4 – Appendix A).

The results of the probit models suggest that the decoupling dummy variable may or may not be endogenous in the per-customer electricity consumption models. The fact that utilities with high per-customer consumption tend to adopt decoupling mechanisms should not cause endogeneity issues because utility-fixed effects are included in the consumption models.[9] In contrast, the suggestion that trends in per-customer consumption may affect a utility's decision to decouple, albeit statistically insignificant, provokes concern about potential endogeneity issues in the models of electricity consumption of Table 1. If this causal relation *does* exist, however, the results of the Table 4 probit models suggest that increasing per-customer electricity consumption *increases* the chances of a utility having a decoupling mechanism. This implies that endogeneity would bias the coefficient of the decoupling variable in the positive direction. Thus, the coefficients of decoupling in the electricity consumption models are either unbiased or closer to zero than the true coefficient. This further strengthens the argument that decoupling mechanisms reduce per-customer residential electricity consumption.

Long Run Implications

The findings in this paper represent short run relationships (<5 years) between decoupling mechanisms and efficiency of residential electricity consumption. There is some reason to believe that these relationships persist, in some magnitude, for an extended period of time. As Jaffe and Stavins (1995) found, DSM investments affect energy consumption for years.

The finding that DSM investment of utilities with decoupling mechanisms causes higher prices (and that higher prices impact demand), however, is innately a short run result. The link between DSM investments of decoupled utilities and price is that, under a decoupling mechanism, reduced demand will cause price to increase with the next scheduled true-up. Once a new rate case occurs, however, new revenue targets and corresponding prices are set by a regulator and are less dependent on previous consumption. Decreased consumption itself may or may not affect the regulator's price decision. Thus, increase in price may only persist until the next rate case (≈3-6 yrs).

[9] The error term in these models only captures utility and time-specific changes in consumption and would not, therefore, be correlated with differences in a baseline month's per-customer electricity consumption across utilities.

Nonetheless, even if the regulator decides to restore prices to their pre-true-up levels, consumption is unlikely to return to the "efficient" market level at this price. Energy efficiency investments and behavior changes cause hysteresis, or history-dependent, effects. If end users respond to high electricity prices by buying energy efficient appliances or making behavioral changes to waste less energy, lower energy prices may not cause them to get rid of their new, efficient appliances or to choose to switch back to wasteful behaviors. Therefore, the effect on demand of higher prices during true-ups may very likely persist through subsequent rate cases.

Conclusions

With widespread concern about global climate change and energy security, the efficacy of mechanisms to improve energy efficiency is of considerable interest. Recent literature on the determinants of energy inefficiency, including consumer choice failure and utility throughput incentives, has especially increased interest in promoting utility involvement in DSM. Decoupling mechanisms are an increasingly popular technique to encourage utility involvement in energy efficiency issues, but little empirical analysis had been conducted into the effects and determinants of decoupling mechanisms on electricity demand. This paper explores this relation using recent utility-level data.

Models of the interplay between utility DSM investment and regulator incentives have important implications on the expected effects of decoupling mechanisms on energy efficiency. These models indicate that decoupling mechanisms only affect investment in DSM investment if additional DSM standards or incentives exist. Moreover, in the presence of standards on DSM spending, decoupled utilities will invest more effectively in DSM than traditionally regulated utilities. Similarly, in the presence of incentives based only on level of DSM spending, decoupled utilities will be more likely to invest in DSM and will do so more effectively than traditionally regulated utilities. Finally, with regulator incentives based on perceived DSM investment efficacy, as inferred from energy demand, decoupled utilities will produce more effective DSM investment than traditionally regulated utilities

Based on these models, this paper explores the hypotheses that decoupling mechanisms decrease residential electricity demand and that this is accomplished through encouraging a greater level of DSM investment, a larger demand-reducing effect of any given level DSM investment, and a price increase that further discourages consumption. This paper theorizes that the effect of decoupling mechanisms is primarily due to its effects on utility DSM investment and its effects on price through DSM investment.

Consistent with the hypotheses, empirical results suggest that decoupling mechanisms are correlated with electricity consumption and price only through their relation with DSM investment. Not controlling for the effects of price and DSM investment, point estimates of the decrease in consumption associated with decoupling mechanisms are quite large and significant at the 5% level. When the effects of decoupling on consumption working through price and DSM investment are eliminated, however, this significance disappears.

As a result of a small sample size, this paper neither affirms nor rejects the hypothesis that decoupling mechanisms increase the level of utility DSM spending. The lack of significance in OLS and tobit models suggests that decoupling mechanisms are not correlated with level of DSM investment. However, the results of a quantile regression, which accounts for the skewed distribution of DSM spending, does suggest that decoupling mechanisms may indeed increase level of DSM speding. More research is needed to thoroughly explore this hypothesis.

Given a fixed level of DSM spending, results strongly suggest that decoupling mechanisms increase the direct demand-reducing effects of DSM spending. A large estimated effect of increased DSM investment of decoupled utilities relative to that of other utilities is found to be significant at the 5% level. This substantiates the result of the theoretical model concerning efficacy of DSM investment. Specifically, the model indicates that DSM investment of decoupled utilities is more effective than that of traditionally-regulated utilities when regulators design DSM investment incentive mechanisms and regulations that are based primarily on level of DSM spending.

This paper also finds weak evidence that decoupling mechanisms increase the efficacy of DSM investment in reducing consumption through the effect of DSM investment on price. DSM investment by decoupled utilities is significantly negatively correlated with price at the 10% level. Higher prices were also found to be very highly correlated with decreased electricity demand.

Tests on pre-2006 data demonstrate that the perceived effect of decoupling mechanisms on electricity consumption is not due to the continuation of pre-existing utility-specific trends in electricity consumption. Probit analyses suggest that the decoupling dummy variable may or may not be endogenous in the per-customer electricity consumption models. However, the sign of the point estimates of the relation between decoupling and DSM suggests that, if anything, the true impact of decoupling on electricity consumption is actually more negative than estimated in this paper. This strengthens the argument that decoupling mechanisms reduce per-customer residential electricity consumption.

While it is reasonably clear that decoupling mechanisms promote more efficient electricity use in the residential sector through more effective utility DSM investment, the link between decoupling mechanisms and level of DSM expenditure remains relatively ambiguous. Collecting DSM spending data for more utilities would improve the estimation of the effect of decoupling mechanisms on level of DSM spending. More in-depth research of the determinants of DSM investment and the specific regulator policies concerning DSM investment would also assist in understanding the interplay between incentive structure, level of DSM investment, and efficacy of DSM investment. With this additional research will come an even greater understanding of the effects of decoupling mechanisms on energy efficiency.

References

ACEEE (American Council for an Energy-Efficient Economy) (2011). "State Energy Efficient Policy Database". American Council for an Energy-Efficient Economy. Available at: http://www.aceee.org/sector/state-policy

Ackerman, Frank and Elizabeth A. Stanton (2008). "What We'll Pay if Global Warming Continues Unchecked." Natural Resource Defense Council Report May 2008. Available at: http://www.nrdc.org/globalwarming/cost/cost.pdf

AGA (American Gas Association) (2007). "Update on Revenue Decoupling Mechanisms." Natural Gas Rate Round-Up April 2007. Available at: www.epa.state.il.us/air/climatechange/documents/subgroups/power-energy/aga-update-on-revenue-decoupling-mechanisms.pdf

Arimura, Toshi H., Shanjun Li, Richard G. Newell, and Karen Palmer (2011). "Cost-Effectiveness of Electricity Energy Efficiency Programs." Resources for the Future Discussion Paper RFF DP 09-48-REV revised April 2011. Available at: http://www.rff.org/RFF/Documents/RFF-DP-09-48-REV.pdf

Asif, M. and T. Muneer (2007). "Energy supply, its demand and security issues for developed and emerging economies." *Renewable and Sustainable Energy Reviews* 11(7): 1388-1413

Auffhammer, Maximilian, Carl Blumstein, and Meredith Fowlie (2008). "Demand Side Management and Energy Efficiency Revisited." *Energy Journal* 29(3): 91–104

Baumann, David (2008). "The Effects of Governmental Energy Efficiency Activities on Electricity Consumption – An Econometric Analysis." LBJ School of Public Affairs

Bhole, Bhurat and Sunita Surana (2011). "Electricity Prices and State Commitment to Energy Efficiency in the U.S." *Energy Efficiency* 4: 9-16

Blomquist, Glenn (1974). "The Effect of Electric Utility Power Plant Location on Area Property Value." *Land Economics* 50(1): 97-100

Boonin, David M. (2009). "A Rate Design to Increase Efficiency and Reduce Revenue Requirements" *Electricity Journal* 22(4): 68-78

Brennan, Tim (2009). "The Challenges of Climate for Energy Markets." RFF Discussion Paper No. 09-32.

Brennan, Tim (2008). "'Night of the Living Dead' or 'Back to the Future'? Electric Utility Decoupling, Reviving Rate-of-Return Regulation, and Energy Efficiency." RFF Discussion Paper No. 08-27.

Brennan, Tim (2009). "Optimal Energy Efficiency Policies and Regulatory Demand-Side Management Tests: How Well Do They Match?" RFF Discussion Paper No. 08-46

Brookings (2011). "Energy Security Initiative." Accessed Nov 2011. Available at: http://www.brookings.edu/projects/energy-security.aspx

Bryce, Robert (2010). "A Bad Bet On Carbon." *The New York Times.* Available at: http://www.nytimes.com/2010/05/13/opinion/13bryce.html

Bureau of Economic Analysis (2011). "Regional Data: GDP & Personal Income." U.S. Department of Commerce accessed Nov 2011. Available at: http://www.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=1

Costello, Ken (2011). "Some Advice to Regulators on Formula Rate Plans." *Electricity Journal* 24(2):44-54

CSI (Center for State Innovation) (2008). "Utility Rate Decoupling: Conserving Energy: A Policy Brief by the Center for State Innovation" Center for State Innovation. Available at: http://www.stateinnovation.org/Publications/All-Publications/Utility-Rate/UtilityRates.aspx

Costa, Dora L, and Mathew E. Kahn (2010). "Why Has California's Residential Electricity Consumption Been So Flat Since the 1980's? A Microeconometric Approach." National Bureau of Economic Research Working Paper 15978.

Edelstein, Paul and Lutz Kilian (2009). "How sensitive are consumer expenditures to retail energy prices?" *Journal of Monetary Economics* 56 (6): 766-779

ECW (Energy Center of Wisconsin) (1997). "Market-Based Utility DSM Programs." Report, Aug 1997. Available at: www.ecw.org/ecwresults/162-1.pdf

EIA (U.S. Energy Information Administration) (1997). "Electricity Pricing in a Competitive Environment: Marginal Cost Pricing of Generation Services and Financial Status of Electric Utilities." Energy Information Administration – Office of Integrated Analysis and Forecasting. Available at: ftp://ftp.eia.doe.gov/electricity/0614.pdf

EIA (U.S. Energy Information Administration) (2011). "Form EIA-826 Data Monthly Electric Utility Sales and Revenue Data." Department of Energy / Energy Information Administration. Available at: http://www.eia.gov/cneaf/electricity/page/eia826.html

EIA (U.S. Energy Information Administration) (2011). "Form EIA-861 Final Data File for 2010." Department of Energy / Energy Information Administration. Available at: http://www.eia.gov/cneaf/electricity/page/eia861.html

Ener Star (2012). "Power Cost Adjustment – Frequently Asked Questions." Accessed Apr 2012. Available at: http://www.enerstar.com/ms_power_cost_adj.html

Energy Star (2012). "Light Bulbs for Consumers." Accessed Feb 2012. Available at: http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=LB

EPA (Environmental Protection Agency) (2007). "Aligning Utility Incentives with Investment in Energy Efficiency: A Resource of the National Action Plan for Energy Efficiency." Environmental Protection Agency. Available at: http://www.epa.gov/cleanenergy/documents/suca/incentives.pdf

Espey, James A., Espey, Molly, (2004) "Turning on the Lights: A Meta-analysis of Residential Electricity Demand Elasticities," *Journal of Agricultural and Applied Economics*, 36(1): pp. 65-81

Eto, Joseph, Steven Stoft, and Timothy Belden (1994). "The Theory and Practice of Decoupling." Lawrence Berkeley Laboratory. Available at: http://escholarship.org/uc/item/9gp741dm;jsessionid=5E68872CEE40922AE7945995A9724D59#page-1

GIllingham, Kenneth, Richard Newell, and Karen Palmer (2009). "Energy Efficiency Economics and Policy." Resources for the Future Discussion Paper 09-13 April 2009

GIllingham, Kenneth, Richard Newell, and Karen Palmer (2006). "Energy Efficiency Policies: A Retrospective Examination." Annual Review Environmental Resources 31:161-92

Glaeser, Edward L, and Mathew E. Kahn (2008). "The Greenness of Cities: Carbon Dioxide Emissions and Urban Development." Working Paper 14238 National Bureau of Economic Research Aug 2008

Graniere, Robert J, Cooley, Anthony (1994). "Decoupling and Public Utility Regulation." The National Regulatory Research Institute Report NRRI 94-14 Aug 1994. Available at: http://nrri.org/pubs/electricity/94-14.pdf

Hausman, Jerry (1979). "Individual Discount Rates and the Purchase and Utilization of Energy- Using Durables." *Bell Journal of Economics*, 10(1): 33–54

Hansen, D.G. (2007). "A Review of Natural Gas Decoupling Mechanisms and Alternative Methods for Addressing Utility Disincentives to Promote Conservation. Utah Department of Public Utilities, Docket No. 05-057-T01, DPU Exh No. 6.1 (DGH-A.1)

Holland, S. P., Mansur, E. T. (2008). "Is Real-Time Pricing Green?: The Environmental Impacts of Electricity Demand Variance." *Review of Economics and Statistics* 90(3): 550-561

Hurley, Doug, Kenji Takahashi, Bruce Blewald, Jennifer Kallay, and Robin Maslowski (2008). "Costs and Benefits of Electric Utility Energy Efficiency in Massachusetts." Synapse Energy Economics, Inc Final Report. August 2008. Available at: http://www.synapse-energy.com/Downloads/SynapseReport.2008-08.0.MA-Electric-Utility-Energy-Efficiency.08-075.pdf

IPCC (Intergovernmental Panel on Climate Change) (2007). "Climate Change 2007: Synthesis Report." IPCC Fourth Assessment Report: Climate Change 2007. Available at: http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains2-1.html

IMF (International Monetary Fund) (2012). World Economic Outlook data. Accessed 2012.

Ito, Koichiro (2010). "Do consumers respond to marginal or average price? Evidence from nonlinear electricity pricing." University of California, Berkeley Draft Paper. Available at: http://ecnr.berkeley.edu/vfs/PPs/ItoKoi/web/JMP_Koichiro_Ito_UC_Berkeley_2010_1122.pdf

Jaffe, Adam B., and Robert N. Stavins (1995). "Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion." *Journal of Environmental Economics and Management* 29(3): 43–63

Joskow, Paul, and Donald Marron (1992). “What Does a Negawatt Really Cost? Evidence from Utility Conservation Programs.” *Energy Journal* 13(4): 41–74

Kahn, Mathew E. and Erin T. Mansur (2011). “Do Local Energy Prices and Regulation Affect the Geographic Concentration of Employment? A Border Pairs Approach.” National Bureau of Economic Research Working Paper 16538 Jun 2011. Available at: ei.haas.berkeley.edu/pdf/working_papers/WP209.pdf

Kihm, Steven (2009). “When Revenue Decoupling Will Work…And When It Won’t.” *Electricity Journal* 22(8): 19-28

Kotchen, Mathew J and Michael R. Moore (2007). “Private provision of environmental public goods: Household participation in green-electricity programs.” *Journal of Environmental Economics and Management* 53: 1-16

Lazer, Jim, Frederick Weston, and Wayne Shirley (2011). “Revenue Regulation and Decoupling: A Guide to Theory and Application.” The Regulatory Assistance Project (RAP) Jun 2011. Available at: www.raponline.org/document/download/id/902

League of Conservation of Voters (2010). “National Environmental Scorecard 09: Second Session 111th Congress,” League of Conservation of Voters. Available at: http://www.lcv.org/scorecard/past-scorecards/pdf/scorecare-2010.pdf

League of Conservation of Voters (2011). “Past Scorecards.” League of Conservation of Voters. Available at: http://www.lcv.org/scorecard/past-scorecards/

Lesh, Pamela G. (2009). “Rate Impacts and Key Design Elements of Gas and Electric Utility Decoupling: A Comprehensive Review.” *Electricity Journal* 22(8): 65-71

Linn, Joshua (2008). “Energy Prices and the Adoption of Energy-Saving Technology.” *The Economic Journal* 118(533): 1986-2012

Loughran, David S., and Jonathan Kulick (2004). “Demand-Side Management and Energy Efficiency in the United States”. *Energy Journal* 25(1): 19–41

Magali Delmas, Michael V. Russo, Maria J. Montes-Sancho (2005). "Deregulation and Resource Reconfiguration In The Electric Utility Industry" University of California Energy Institute April 2005. Available at: http://www.ucei.berkeley.edu/PDF/EPE_012.pdf

McCarthy, Kevin E. (2009). "Electric Rate Decoupling in Other States." OLR Research Report Jan 2009. Available at: http://www.cga.ct.gov/2009/rpt/2009-R-0026.htm

McKinsey & Company (2007). "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?" US. Greenhouse Gas Abatement Mapping Initiative Executive Report

Meneken H.L. (2007). "Revenue Decoupling: A Policy Brief of the Electricity Consumers Resource Council." The Electricity Consumers Resource Council Jan 2007

Michelfelder, Richard (1993). "Evolving Electric Utility Regulatory Policy: Internalizing the Social Costs of Production." *The American Journal of Economics and Sociology* 52(2) 227-239. Available at: http://www.jstor.org/stable/3487062

Moore, Thomas G. (1970). "The Effectiveness of Regulation of Electric Utility Prices." *Southern Economic Journal* 36(4): 365-375

Musti, Sashank, Katherine Kortum, and Kara M. Kockelman (2011). "Household energy use and travel: Opportunities for behavioral change." *Transportation Research Part D* 16 49-56.]

NARUC (National Association of Regulatory Utility Commissioners) (2007). "Decoupling of Electric & Gas Utilities: Frequently Asked Questions (FAQ)." National Association of Regulatory Utility Commissioners 2007. Available at: http://www.naruc.org/Publications/NARUCDecouplingFAQ9_07.pdf

National Weather Service Climate Prediction Center (2012)."Degree Days Statistics." Accessed Feb 2012. Available at: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/

Parformak, Paul W., and Lester B. Lave (1996). "How Many Kilowatts Are in a Negawatt? Verifying 'Ex Post' Estimates of Utility Conservation Impacts at the Regional Level." *Energy Journal* 17(4): 59–88

PSC (Delaware Public Service Commission) (2007). "Before the Public Service Commission of the State of Delaware, in the Matter of the Investigation of the Public Service Commission into Revenue Decoupling Mechanisms for Potential Adoption and Implementation by Electric and Natural Gas Utilities Subject to the Jurisdiction of the Public Service Commission". PSC Regulation Docket No. 59 Mar 2007

PSC (Public Service Commission of Wisconsin) (2001). "Typical Steps in a Major Rate Case." Public Service Commission of Wisconsin. Available at: psc.wi.gov/thelibrary/publications/general/general04.pdf

PUCO (Public Utilities Commission of Ohio) (2011). "Rate Case Process." Public Utilities Commission of Ohio accessed Oct 2011. Available at: http://www.puco.ohio.gov/puco/index.cfm/consumer-information/consumer-topics/rate-case-process/

Saad, Lydia (2011). "In U.S., Expanding Energy Output Still Trumps Green Concerns." Gallup. Mar 2011. Available at: http://www.gallup.com/poll/146651/Expanding-Energy-Output-Trumps-Green-Concerns.aspx

Smil, Vaclav (2011), Energy Transitions: History, Requirements, Prospects. Praeger.

Stern, N. (2008). "The Economics of Climate Change." *American Economic Review* 98(2): 1-37

Train, Kenneth E. and Judi E. Strebel (1987). "Energy Conservation and Rebates in Commercial Food Enterprises." *American Agricultural Economics Association* 69(1): 106-114

Appendix A –Model Results

Table 1:

REGRESSIONS OF LOG RESIDENTIAL ENERGY CONSUMPTION PER CUSTOMER

	(1) OLS	(2) 2SLS	(3) 2SLS - Robustness	(4) Pre-existing Trend
Decoupling	-0.05**	-0.01	-0.01	x[10]
	(-2.509)	(-0.550)	(-0.600)	
DSM	x	0.34[11]**	0.37[11]**	0.10[12]
		(2.283)	(2.390)	(0.964)
Decoupling*DSM	x	-0.39[11]**	-0.41[11]**	x
		(-1.981)	(-2.005)	
Res. Customers	-1.00***	-1.00***	-1.00***	-1.00***
	(-405.390)	(-407.717)	(-407.849)	(-743.815)
Electricity Price	x	-1.47***	-1.42***	-0.11
		(-3.185)	(-3.039)	(-0.090)
Natural Gas Price	-0.12[11]	0.08[11]	0.06[11]	0.13[11]
	(-0.712)	(0.444)	(0.355)	(0.992)
GDP	0.25**	0.26***	0.24***	-0.13
	(2.576)	(2.785)	(2.788)	(-0.679)
Pop	0.09	0.07	0.07	0.34*
	(0.941)	(0.716)	(0.744)	(1.913)
Personal Income	-0.27[11]	-0.22[11]	-0.22[11]	-0.94[11]***
	(-1.610)	(-1.296)	(-1.219)	(-6.909)
EERS	0.01	0.02	x	0.01
	(0.794)	(1.320)		(0.786)
Env. Sensitivity	0.03[11]	0.02	x	-0.02
	(1.208)	(0.928)		(-1.209)
CDD	0.11[11]***	0.11[11]***	0.11[11]***	0.12[11]***
	(13.443)	(13.338)	(13.368)	(27.607)
HDD	0.02[11]***	0.02[11]***	0.02[11]***	0.04[11]***
	(5.463)	(5.248)	(5.243)	(28.215)
Year	x	x	x	0.02**
				(2.394)
Year*Decoupling	x	x	x	0.01**
				(2.082)
Controlled for Utility	√	√	√	√
Controlled for Time	√	√	√	x
Constant	2.70**			
	(2.465)			
N	44,718	44,656	44,656	21,263
R^2	0.986	0.977	0.977	0.983

t-statistics clustered on utility in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[10] Omitted because of collinearity
[11] Coefficient multiplied by 100

Table 2:

Regressions of Log Total Annual Utility DSM Expenditures

	(1) OLS	(2) Tobit	(3) Quantile
Decoupling	0.04	0.05	0.34*
	(0.074)	(0.090)	(1.855)
Res. Customers	-0.01	-0.00	-0.00
	(-0.147)	(-0.084)	(-0.169)
GDP	1.86	2.51	-0.11
	(0.581)	(0.668)	(-0.204)
Pop	1.04	1.39	1.78*
	(0.250)	(0.303)	(1.836)
Personal Income	-0.09	-0.15	0.00
	(-0.578)	(-0.788)	(0.000)
EERS	1.96	2.02	0.72***
	(1.415)	(1.423)	(2.804)
Env. Sensitivity	0.01	0.01	0.00
	(1.004)	(1.194)	(0.315)
CDD	0.00	0.00	-0.00
	(0.379)	(0.415)	(-0.000)
HDD	-0.00	-0.00	-0.00
	(-0.157)	(-0.139)	(-0.000)
Controlled for Utility	√	√	√
Controlled for Time	√	√	√
Constant	-13.98	-21.38	9.01
	(-0.413)	(-0.533)	(1.569)
N	1,502	1,502	1,501
(Pseudo) R^2	0.901	0.291	0.727

t-statistics in parentheses (clustered on utility for OLS and Tobit)
*** p<0.01, ** p<0.05, * p<0.1

Table 3:

First-Stage Regressions of Residential Electricity Price

	(1)	(2)	(3)
Decoupling	0.00	0.01*	0.00
	(0.772)	(1.849)	(0.718)
DSM	-0.00	x	0.00
	(-0.167)		(0.050)
Decoupling*DSM	0.10[12]*	x	0.10[12]
	(1.699)		(1.648)
Res. Customers	-0.00	-0.00	-0.00
	(-0.516)	(-0.463)	(-0.559)
Natural Gas Price	0.04[12]***	0.04[12]***	0.04[12]***
	(3.761)	(3.608)	(3.531)
GDP	0.00	0.00	-0.00
	(0.082)	(0.176)	(-0.129)
Pop	-0.02	-0.02	-0.02
	(-0.991)	(-1.081)	(-1.009)
Personal Income	0.03[12]*	0.03[12]*	0.03[12]*
	(1.881)	(1.850)	(1.949)
EERS	0.00	0.00	x
	(1.141)	(1.128)	
Env. Sensitivity	0.01[12]	0.01[12]	x
	(1.537)	(1.512)	
CDD	0.00	0.00	0.00
	(0.287)	(0.295)	(3.531)
HDD	-0.01[12]***	-0.01[12]***	-0.01[12]***
	(-5.585)	(-5.581)	(-5.622)
% Gen Coal*Price Coal	0.02[13]**	0.02[13]**	0.02[13]**
	(2.459)	(2.485)	(-3.585)
% Gen Gas*Price Gas	0.04[13]***	0.04[13]***	0.04[13]***
	(9.317)	(9.316)	(2.394)
% Gen Oil*Price Oil	-0.02[13]***	-0.02[13]***	-0.02[13]***
	(-4.942)	(-4.979)	(9.319)
% Gen Renew*Price Coal	-0.03[13]***	-0.03[13]***	-0.03[13]***
	(-3.551)	(-3.689)	(-4.926)
Controlled for Utility	√	√	√
Controlled for Time	√	√	√
Constant	0.13	0.12	0.16
	(0.996)	(0.925)	(1.211)
N	44,656	44,656	44,656
R^2	0.900	0.900	0.900

t-statistics clustered on utility in parentheses

*** p<0.01, ** p<0.05, * p<0.1

12 Coefficient multiplied by 100

13 Coefficient multiplied by 10,000

Table 4:

PROBIT REGRESSIONS OF PROBABILITY OF DECOUPLING

	(1)	(2)	(3)
Res. Sales per Customer - 2001	0.23***	0.28***	0.23***
	(3.097)	(3.333)	(2.929)
Res. Customers - 2001	0.18***	0.20***	0.19***
	(2.672)	(2.627)	(2.668)
GDP per capita - 2001	2.28**	2.80***	2.29**
	(2.569)	(2.690)	(2.575)
Personal Income - 2001	-0.15	-0.11	-0.14
	(-1.138)	(-0.712)	(-1.094)
EERS - 2001	-0.38	0.59	-0.38
	(-1.148)	(1.203)	(-1.130)
Env. Sensitivity - 2001	0.01**	0.01**	0.01**
	(2.141)	(2.087)	(2.153)
CDD - 2001	0.14[14]	0.12[14]	0.13[14]
	(1.265)	(0.929)	(1.269)
HDD - 2001	-0.01[14]	-0.01[14]	-0.01[14]
	(-0.330)	(-0.136)	(-0.319)
Electricity Price - 2001	5.07	3.20	5.01
	(1.220)	(0.653)	(1.199)
% Gen from Coal - 2001	-0.01	-0.01	-0.01
	(-1.581)	(-1.254)	(-1.591)
% Gen from Gas - 2001	-0.01	-0.02*	-0.01
	(-1.314)	(-1.724)	(-1.310)
% Gen from Renewables - 2001	-0.01	-0.01	-0.01
	(-0.822)	(-0.718)	(-0.839)
Δ[15] Res. Sales per Customer	x	0.56	0.02
		(0.995)	(0.288)
Δ Res. Customers	x	0.56	x
		(0.978)	
Δ GDP per capita	x	5.21	x
		(1.522)	
Δ EERS	x	1.67**	x
		(2.313)	
Δ Env. Sensitivity	x	0.01	x
		(.721)	
Δ Electricity Price	x	9.01	x
		(1.247)	
Constant	-26.24***	-32.68***	-26.42***
	(-2.783)	(-2.898)	(-2.793)
N	384	384	384
Pseudo R^2	0.347	0.421	0.348

z-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[14] Coefficient multiplied by 100
[15] $\Delta = \text{value}_{2005} - \text{value}_{2001}$

Appendix B – Variable Descriptions

Residential electricity consumption per customer ~ In accordance with the techniques of Arimura et al. (2011) and Loughran and Kulick (2004), variables on monthly residential energy consumption per customer for each utility and year were calculated from monthly energy consumption data from Form EIA- 826 and annual energy customer by sector data from Form EIA-861. For each utility, year, and sector, monthly consumption data were divided by the corresponding number of customers for that year to attain estimated electricity consumption per customer. Consumption is measured in megawatt hours (MWh). This analysis uses the natural logarithm of the residential electricity consumption per customer. This study uses nominal consumption, although the use of real consumption would not alter the results due to linearity of the logarithmic function[16].

DSM ~ Data on annual total utility spending on DSM programs (measured in dollars) were extracted from Form EIA-861. This variable should reflect all of a utility's nominal spending – direct and indirect – in a given year on DSM programs. To keep utilities with $0 DSM expenditure in the data, the variable used in the analysis is the natural logarithm of 1+nominal DSM spending.

In theory, the DSM variable should capture only spending on residential DSM and should be measured per residential customer. Unfortunately, DSM spending was not broken down by sector for most of the years in this study. Data on the breakdown of DSM expenditures by utility in 2010, however, are available. In 2010, less than half of DSM expenditures were used for programs in the residential sector. This introduces considerable measurement error in the measure of DSM.

DSM spending data is missing for some utilities in some years in EIA Form EIA-861. This is presumably because many utilities chose to withhold information on their DSM spending from the EIA during years when their spending is low or

[16] log(real consumption) = log(nominal consumption/price index) = log(nominal consumption) – log(price index) = log(nominal consumption) – c_1. If log(real consumption) = BX + c_2 , then log(real consumption) = BX + (c_1 + c_2) = BX + c_3 where c's denote constants. Thus, only the constant term is affected by this choice.

nonexistent. In this paper, we assume that utilities who do not submit information on their DSM spending had no DSM spending.

Preliminary analysis experimented with the natural logarithms of 1+total DSM expenditure and 1+DSM expenditure per customer. Both have obvious flaws. Which is better depends on the nature of changes in utility DSM spending over time. The results when DSM is the *dependent* variable are similar regardless of choice of measure. When DSM is used as an *explanatory* variable, preliminary analysis suggested that the former measure had greater explanatory power and is therefore the focus of this analysis.

Decoupling ~ A dummy decoupling variable was created using information from ACEEE and from various online dockets. This variable takes the value 1 if the specified utility had any type of decoupling mechanism in place in the given month and year, and it takes the value 0 otherwise.

Residential Customers ~ Annual data on number of residential customers per utility were retrieved from Form EIA-861. The natural logarithm of number of customers was used in this analysis.

Electricity Price ~ Monthly utility electricity residential retail prices were retrieved from Form EIA-826. Prices are in units of $/kWh.

Retail Natural Gas Price ~ Following the literature, natural gas price is included in the models because it is a potential substitute for electricity. Monthly residential natural gas prices by state were acquired from the EIA Natural Gas Prices Residential Price Data Series. Natural gas prices are in dollars per cubic feet.

GDP ~ In keeping with Arimura et al. (2011) and Loughran and Kulick (2004), data on annual nominal GDP per capita by state were retrieved from the Bureau of Economic Analysis for the years 2001-2010. GDP is measured in thousands of current dollars. The natural logarithm of GDP was used in the analysis. Each annual value was used for all monthly observations in a given state and year.

Quarterly Personal Income ~ Data on state quarterly personal income in millions of nominal dollars were obtained from the Bureau of Economic Analysis. The natural logarithm of personal income was used in this analysis.

Pop ~ A variable for annual population was computed using annual state GDP and annual per-capita state GDP from the Bureau of Economic Analysis. The natural logarithm population was used in the analysis. Each annual value was used for all monthly observations of consumption in a given state and year.

EERS ~ A dummy variable for whether or not the state had an Energy Efficiency Resource Standard in place during the given month and year was generated based on data from ACEEE and various dockets.

Environmental Sensitivity ~ Using similar methods to those of previous studies on electricity consumption (Delmas et al. 2005, Arimura et al. 2011), an annual environmental sensitivity rating was calculated for each state based on scores from the League of Conservation Voter's National Environmental Scorecards. This rating averages the League of Conservation Voter's mean scores of the politicians in the house and in the senate of each state. The ratings are on a scale of 0 to 100 and are based on how the politicians vote on key environmental legislation.

CDD and HDD ~ Population-weighted monthly heating and cooling degree days by state were compiled from the National Weather Service Climate Prediction Center archived degree days statistics. Experiments with various climate indicators and functional forms of CDD and HDD suggest that the respective linear models best capture the relation between climate and per capita energy consumption.

% Generation from Oil/Coal/Gas/Renewables ~ These variables represent the percentage of electricity in the given state that was generated in 2005 using each of oil, coal, natural gas, and energy from various renewable energy sources, respectively. These data were retrieved from the EIA website.

US Oil/Gas/Coal Prices ~ These series reflect the input prices faced by producers of electricity. The series were procured from the EIA website. US oil refiner prices and natural gas city gate prices were available on a monthly level. US coal prices were only available on the annual level.

Australian Thermal Coal Price ~ Monthly data on Australian thermal coal price, a prominent coal price index, were taken from the International Monetary Fund. Prices are in U.S. dollars per metric ton.

i.Time ~ Each observation of the variable, *time*, represents the month (ex- February 2001) when the corresponding consumption occurred. This variable was partitioned into 119 variables, one for each of the months except for January 2001. Together, these variables capture all nationwide time and seasonal discrepancies.

i.Utility ID ~ Each utility in the U.S. has a unique identification number. Data on the variable, *Utility ID*, were retrieved from Forms EIA-826 and EIA-861. It distinguishes each utility in the datasets from other utilities. Additional, unofficial ID's were created for utilities that extended to multiple states to enable these entities to be treated as unique utilities. One dummy variable was created for each utility. For each observation, the value of one of these variables is one and the values of the rest are zero.